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ORDINARY MEETING.

13 January, 1942.

Professor CHARLES EDWARD INGLIS, O.B.E., M.A., LL.D., F.R.S., President, in the Chair.

The Council reported that they had recently transferred to the class of

Members.

Duncan Campbell Berry, B.Sc. (*Leeds*).
Ernest Alexander Black.
William Brown.
William Spottiswoode Cameron.
Hugh Morton Gibb.
John Bickett Harvey.
Johannes Adrianus van Heel, B.Sc. (Eng.) (*Lond.*).
Leslie Frank Hobbs, B.Sc. (*Bristol*).
James Reginald Walter Saunders, B.Sc. (*Glas.*).
Herbert Alfred Sieveking, M.Sc. (Eng.) (*Lond.*).

And had admitted as

Students.

William Henry Adams.
Robert Granville Alcock.
William Stanley Allen.
Richard Haworth Aspden.
John Smith Balfour.
Roy Anthony Baxter.
Eric James Berrisford.
Alexander William Birrell.
Cecil Moncur Bolt.
Douglas Bond.
Alan John Boyce, B.Sc. (*Bristol*).
Joseph Douglas Boyd.
Cyril Douglas Brown.
Robert Robson Brown.
Cecil Henry Burrows.
Robert Cannon.
James Cattanach.
John Chappell.
Alfred John Cockram.
John Stanley Cording.
Charles McKenzie Cullen.
Derrick Richard Day.
Ian Buchan Donald, B.A. (*Cantab.*).
Kevin Brendan Mary Drane.
John Jonathan Elven.
Illakuttige Aloysius Fernando.
James Patrick Anthony Derrick Fernando.
William Ronald Flockhart.
Donald Ian Fraser.
Hamilton Irvine Gillis.
Russell Godfrey Goldman.
Donovan Graeme-Cook.
John Norman Gray.
Keith James Gray.
Robert Martin Gray.
Peter Meredith Grinstead.
Michael Gross, B.Sc. (*Cape Town*).
William Joseph Guckian.
Richard Frank Guillaume.
Thomas Harley Haddow.
Denis Arthur Russell Hall.

Enderby Frank Handson.
Stuart Beaumont Hart.
James Hay.
Wynyard Russell Haynes.
Kenneth Charles Hayson.
Donald Wallis Herd.
Raymond Brian Hill, B.Sc. (*Bristol*).
Graeme Scott Hogg.
Stanley Gordon Holt.
Randal Thomas Huston.
John Edward Hutton.
Ian James Macleod Innes, M.A. (*Edin.*).
George Edward William Jackson.
Robin Mackie Kerr.
Joseph Norman King.
Johnston Stewart Lamb.
John Crabbe Lambert.
David Peter Landreth, B.Sc. (*St. Andrews*).
Denis Lee.
William Thomas Liggett.
Denis Charles William Lippard.
Hugh Garside Llewellyn.
Thomas Jackson McCormick.
William Gerrard McCusker.
John Douglas McIntosh.
James McKean.
Alastair Munro Mackie.
Sant Malkani.
Colin McDonald Matheson.
James Mackenzie Maxwell.
John Alexander Walker Miller.
Derek Stuart Russell Moon.
Antony Charles Morris.
Guy Moss.
Charles Clements Murphy.
Hugh McDowall Nelson.
James Harold Norris.
Norman Arthur Oldham.
William George Allen Port.
George Christopher Poston.
Gilbert Pott.
John Stewart Pow.
Jack Briggs Priestley.
Barclay Broadberry Queen.
Kenneth David Raithby.
Alexander Steel Ralston.
Trevor John Ransley.
Evan Thomas Treharne Rees.
Alexander Sydney Walter Rhind.
Jack Robertshaw.
Edwin Peter Rolfe.
Harold Rowling.
Thomas Aloysius Ryan.
Barry Charles Wilton Sanger.
Anthony Graham Clease Sheldon.
Eric Arthur Stanley.
John Helm Willshaw Stevenson.
Samuel Hoy Stevenson.
George Fielding Stewart, B.Sc. (*St. Andrews*).
Dennis Sullivan.
Leslie James Sutherland.
James Victor Tagg.
George Peter Proctor Talbott.
Donald MacRae Tindell.
John Tiplady.
Geoffrey Washington Trevelyan, B.A. (*Cantab.*).
William Turner.
John Hollett Walker.
John Leslie Walton.
Alfred Robert Watson.
Kenneth Harold White.
John Miles Whiteley.
John Keith Bainbridge Willis.
James Blyth Wood.
Peter Garnett Wright.

The Scrutineers reported that the following had been duly elected as

Members.

James Percy Hallam.
Alfred Raworth.

Associate Members

Richard Adams.
George Kent Armstrong, B.E. (*New Zealand*), Stud. Inst. C. E.
Emile Henry Newell Augier.
Kenneth Alan Ballinger, Stud. Inst. C.E.
Charles Bernard Barlow, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Thomas Bedford.
Kenneth Matthew Beer.
Lindsay Barrett Boyce.
Colin Brown, B.Sc. (Eng.) (*Lond.*).
William Buckle.
James Busby, B.Sc. (*Birmingham*).
Kaikhushru Behramshaw Carnac, B.E. (*Bombay*).
Peter Francis Carter, B.Sc. (Eng.). (*Lond.*), Stud. Inst. C.E.
Pestonji Jehangirji Darukhanavala, B.E. (*Bombay*).
Alfred George Davenport.
George Davie.
Balaji Narasingha Rao Desai, B.E. (*Mysore*).

LANCELOT SMITH DODD, B.Sc. (Eng. (*Lond.*).
DESMOND DURKIN, B.Sc. (*Manchester*), Stud. Inst. C.E.
JOHN CRISTOPHER GUINNESS DU TOIT, B.Sc. (*Cape Town*).
CECIL DUTTON, B.Sc. (*Manchester*), Stud. Inst. C.E.
HUGH FORD, Ph.D., B.Sc. (Eng.) (*Lond.*.)
EDWARD ENOS FRASER, B.Sc. (Eng.) (*Lond.*).
JOHN BAPTISTE GIUSTO.
ERIC BLAKELEY GLOVER.
GEORGE BERNARD GODFREY.
JOHN FERDINAND GREINIG.
GEORGE ERNEST HIGGINS.
HUGH COLUMBA HILL, B.Sc. (*Belfast*).
NORMAN HOLMES.
EDWARD FREDERICK HOPE-JONES, M.A. (*Cantab.*).
PAUL DION JANSZ.
GEOFFREY MILES JOHNSON, B.A. (*Cantab.*).
JAMSHEDJI CAWASJI KARKARIA, B.E. (*Bombay*).
GOVIND JEEJAVI KULKARNI, B.E. (*Bombay*).
RANJIT KUMAR, B.Sc. (Eng.) (*Lond.*).
GUY ASHFORD LAURENCE, Stud. Inst. C.E.
JAMES MCCUSKER, B.Sc. (*Glas.*).
MICHAEL JAMES MCENTEE, B.E. (*National*).
JAMES GEOFFREY MCLELLAN.
ARCHIBALD VERNON MCQUARRIE, B.Eng. (*Liverpool*).
BIRENDRA NATH MAJUMDAR, B.Sc. (*Calcutta*).
WILLIAM GORDON MARTIN, Stud. Inst. C.E.
DONALD BRENDAN MURPHY, B.E, B.Sc. (*N.U.I.*)
FREDERICK DONALD PEACOCK, B.Sc. (Eng.) (*Lond.*).
CYRIL WILFRED PUGH, B.Sc. (Eng.) (*Lond.*).
JAMES GRIFFITH ABIATHAR PUGH, B.Sc. (*Wales*).
WILFRID ALAN RENDLE, B.Sc. (Eng.) (*Lond.*).
JOHN VICTOR GARLAND SHILSTON, Stud. Inst. C.E.
ARTHUR PHILIP SHRIMPTON, B.Sc. (*Birmingham*).
ANDREW SIM, B.Sc. (*Edinburgh*).
NICHOLAS STATHE.
COLIN HUGH STEVEN, B.Sc. (*Bristol*).
JOHN ALWYN THRALL, Stud. Inst. C.E.
NORMAN FREDERICK TRUSCOTT, Stud. Inst. C.E.
DOUGLAS WALPOLE, Stud. Inst. C.E.
STANLEY MACDONALD WILKINSON, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
DAVID IVOR WILLIAMS, B.Sc. (*Wales*).
JACKSON MCLAREN WINT, B.Sc. (Eng.) (*Lond.*).
PHILIP GEORGE WORLEY, Stud. Inst. C.E.

JAMES FORREST LECTURE, 1942.

The President said that members had assembled that afternoon on the occasion of the Forty-eighth James Forrest Lecture. Perhaps it was unnecessary for him to remind the audience that the James Forrest Lectures were designed to give members of The Institution an opportunity of absorbing the wisdom of authorities on subjects which, although related to engineering, might perhaps be a little outside the everyday path trodden by engineers when pursuing their normal activities. In recent years members had had their interests and understandings quickened by such eminent scientists as Sir William Bragg, Sir Frank Smith, Sir Edward Appleton, and Professor Andrade. Each of them in his own particular field had dealt with the physical properties of materials and had brought members' conceptions up to date regarding the structure of matter, both in its solid and gaseous state. On the present occasion they were breaking new ground and their distinguished Lecturer, Dr. Myers, would deal with the human rather than the materialistic side of engineering, the subject of his address being " Psychology as applied to Engineering."

The President had had the pleasure of knowing Dr. Myers for many

years, and knowing him as a man with profound and liberal human sympathies, and that endearing characteristic added to his high intellectual and research qualifications had won for him a unique position as our outstanding authority on industrial psychology. For evidence of his exalted rank one had only to note the long pennant of distinctions and degrees he was entitled to fly from his masthead—degrees almost as numerous as those appertaining to a Centigrade thermometer, and among numerous important positions he had held, he was the first President of the British Psychological Society. The President anticipated that in his Address Dr. Myers would stress the extreme importance of ethical development in shaping the course of human progress. He knew full well that Dr. Myers did not regard the mere mechanization of mankind or the extraction of the last foot-pound of energy out of every worker as the ultimate goal of the science he had developed. Furthermore, he felt that Dr. Myers had little or no sympathy with that galley-slave technician—politely termed the " Efficiency Engineer ", with his ideal of taking every manual worker and gearing him up to an efficiency of 100 per cent. or more ! He was certain Dr. Myers had little sympathy with that point of view.

All knew that deep rooted in humanity there were many imponderables, subtle predilections, and aversions which it was the duty of management to discover, respect, and take into serious account, and it was a mere truism to state that monetary reward was not the only urge which would produce enthusiastic and efficient service.

He felt sure that all would leave that room re-humanized, with many new thoughts, ideals, and inspirations, and he had much pleasure in calling upon Dr. Myers to deliver his address.

"Psychology as applied to Engineering."

By Charles Samuel Myers, C.B.E., M.A., M.D., Sc.D., F.R.S.

Introduction.

The first of the annual James Forrest Lectures, established in honour of one who, throughout a period of 58 years, was successively Secretary and Honorary Secretary to this Institution, was delivered in 1893. That which I am privileged to give to-day would therefore have been the fiftieth lecture of this series, had it been continued every year without interruption. By a strange coincidence this year signalizes also the jubilee of the teaching of one of the youngest branches of natural science in Great Britain : the first systematic course of instruction in this country provided in experimental psychology was given likewise in 1893, by the late Dr. W. H. R. Rivers at Cambridge. Of course, the study of the human mind dates from much earlier times, but it was then seldom

undertaken in an experimental manner. Contemporary knowledge of psychology had also long before been applied—but again not by scientifically controlled methods—to relevant problems in the fields of medicine, education, and aesthetics.

Aesthetics and Engineering.

To aesthetics, in its psychological relations to engineering, I first turn, partly because the Institution of Civil Engineers has of late shown a special interest in this subject, realizing more fully than before that it is a function of the engineer to provide the community with objects which are not merely useful and efficient, but are also, as far as possible, beautiful in appearance and in harmony with their surroundings. I have given this subject first place in my Lecture also because the psychologist has long been engaged in endeavouring to ascertain—it must be admitted with far from complete success—the nature of beauty and the conditions, both mental and environmental, under which our individual experiences of beauty occur.

The psychologist has come to recognize the unique, specific nature of beauty, and, at the same time, its several varieties and the vastly different kinds of " objects " that may evoke it, these " objects " ranging from a warm bath, a glass of vintage port, a surface of uniform colour, an expert's bodily movements, a moral act or state (for example, of heroism, forgiveness, love, or gratitude), a mathematical solution, a scientific experiment, a bridge, engine or machine—ranging from all these to a picture, statue, building, symphony, opera, ballet, piece of prose, poem, or drama. Every one of them may, under certain conditions, be experienced as beautiful, endowed with sensual, perceptual, intellectual, or moral beauty according to the nature of the " object."

What is merely agreeable or pleasing is, of course, not necessarily beautiful: indeed probably by large numbers of people beauty is but rarely—at all events intensely—experienced. They often confuse beauty with other, humbler, experiences such as prettiness; or they may apply to an object the term " beautiful " not because it does, but because it might, arouse the feeling of beauty, just as a given situation is often termed " interesting " without at the moment actually exciting interest. And what appears to us as constructed with amazing simplicity or technical perfection, or as frankly and clearly expressing the function for the performance of which it has been designed—this also is not necessarily beautiful. Our experience of beauty seems to depend rather upon the presence in us of a specific " aesthetic " mental " set " or " attitude," of the nature and conditions of development of which we know as yet little. We can, however, at once recognize one psychological result of that attitude, namely, our projection of the feeling of beauty into the external object that has evoked it, so that the beauty seems to us to reside in that

object and not, as it really resides, in ourselves in consequence of our internal mental activity. Herein beauty differs from most other feelings; for example, we do not regard our emotions of fear or anger as resident in the external object or situation that provokes them.

It is true that we may enumerate in the physical world certain aesthetic "principles", for example, of formal proportion, balance, rhythm, harmony, symmetry, contrast, and unity—even mathematically describable relations—which experience shows to be favourable for the arousal of perceptual beauty. In a certain sense, therefore, but with little regard for strict accuracy, the perceived object may be said to carry to the percipient potentially a "message" of beauty. In some respects these aesthetic principles resemble the metrical and other classical rules of poetical composition: they may all be obeyed and yet the object may fail to evoke beauty, partly because obedience to rules may be aesthetically insufficient or even unnecessary, and partly because the percipient lacks that peculiar aesthetic set or attitude in which alone the actual experience of beauty is possible. Beauty, therefore, cannot be assured by specified external devices: indeed—alike in creation and in appreciation—it may come to us unsought through unpremeditated mental activity.

Adopting this aesthetic attitude, we frequently also project, besides beauty, other of our experiences into the "object." We come to endow it with other human qualities and characters, to "personalize" it and to regard it as something existing, as it were, for itself alone—that is to say, as an independent, self-active "subject", rather than as an inanimate "object" of practical worth. Thus we may ascribe to it the human traits of dignity, sincerity, joviality, daintiness, etc. (or the reverse). In this sense it has been said [1] that we "distance" the art-object. And having thus "distanced" it, we proceed, to a varying extent, to become aesthetically "absorbed" in it, to steep ourselves in it—it may be to lose ourselves so completely as to fall into a state bordering on ecstasy.

These acts of "distancing" and subsequent "absorption" are only perfectible when all notions of the serviceableness of the object to us are banished. The sense of beauty, for example, felt for the fair body of a nude woman tends to disappear as soon as sexual desires are roused. So, too, we come to regard the architect as a craftsman rather than as an artist, when the use and purpose of his building for our own ends obtrude themselves too strongly. On the other hand, when we "personalize" the art-object; when we treat it as an independent "subject" endowed with human characters; when, for example, we think how gracefully, majestically, or easily an engineering product fulfils its own life-like functions; such thoughts may well conduce to the experience of beauty—as indeed, conversely, will the realization of its unfitness impede the experience of beauty. Their help is clearly illustrated in the beauty that can readily

[1] Edward Bullough, "'Psychical Distance' as a Factor in Art and an Aesthetic Principle," *Brit. J. of Psychol.*, vol. v, pp. 87–118 (1912).

be evoked in us by the modern locomotive, the modern aeroplane, or the modern motor-car, especially when contrasted with their earlier and more clumsy forms. In the evolution of the present designs of these objects, generations of engineers have, usually at least, had no aesthetic interests. They have merely employed with increasing success the most efficient material that they have available, in fitter, neater, and more economic ways, gradually eliminating needless excrescences and obtaining the maximum of power and function with apparently the minimum of effort, whilst at the same time unwittingly improving the form of their structure as they " feel " more intimately and with greater knowledge—even " feel themselves into "—the properties, possibilities, and demands of their ever-changing medium which, in so far as such self-subjection occurs, becomes, in a sense, their master.

If, as I have urged, the scientific or practical and the aesthetic attitudes are simultaneously inimical to one another, the engineer may escape from this difficulty by designing a structure initially from the engineering aspect, and then submit his design to the architect, asking him—or he may himself consider sooner or later—what changes in form are desirable in order to make it at least more agreeable to the eye. But the dangers of such patchy, last-minute " tinkering " are avoidable if the architect and the engineer are in close, uninterrupted partnership from the start, or if the engineer has some aesthetic " talent ", or often merely a knowledge of aesthetic principles and some experience of their use. Then, by repeated oscillations between the two attitudes, he will receive some aesthetic guidance throughout the development of his original design. More or less intuitively, but also in part deliberately, he will far better succeed in producing a structure that is both efficient and, at least, not unsightly: he may indeed produce one that appears even beautiful to himself and others.

Alike in the creation and in the appreciation of the beautiful, the development of the aesthetic attitude depends partly also upon other and deeper unconscious mental activities of which at present we have far from complete knowledge. These play a specially important role in the creation of the beautiful. Ordinarily it results, as I have just said, from the more or less intuitive or deliberate use of aesthetic *talent*. But artistic creation arises also as an unexpected uprush of aesthetic *genius* from the unconscious—a sudden " inspiration ", as we call it. If the engineer is endowed with this creative genius of the true artist, he will have long ruminated consciously upon the scientific conditions and practical needs that have to be satisfied in his intended structure; and then, after a period of " incubation ", he will suddenly receive an inspiration of beauty that reveals the form which his design should take. Like other artists, he will thereupon set himself skilfully to express his inspiration, paying due regard to the properties and limitations of his " material " and to practical needs of other kinds. These, of course, differ widely in kind and com-

plexity for the engineer from their significance for the painter, sculptor, poet, or musician.

Although they are simultaneously inimical to one another, we may oscillate, as I have indicated, between the scientific or practical attitude, on the one hand, and that of aesthetic appreciation, on the other. Therefore their incompatibility does not justify us in regarding the aims of engineering and aesthetics as belonging to two distinct vocations. For better or for worse in its long history, artistic production has usually had to serve two masters, the artist who is "out" for self-expression and for "art for art's sake," and the receptive society in which he lives. There are many well-known instances where the artist's products have been unintelligible to his own generation, hide-bound by social culture, tradition, and convention; and their beauty, therefore, has not been appreciated until later. But in other ways the artist has always been called on to render social service. In prehistoric times the marvellously beautiful cave-paintings of animals were in all probability designed with the magical purpose of obtaining food. In mediaeval times artistic creation often served, under Church patronage, a religious purpose. At the present day social needs demand the co-operation of artistic and engineering ability. In their abstract forms, the conflict between art and science must be eternal. Just as the pure scientist carries out his laboratory research regardless of its social value, so the pure artist will work solely for his "selfish" expression. But in the more applied, social, forms of art and science, a compromise must be somehow effected without too serious loss to either.

It is true that a knowledge of the principles of aesthetics will not make the engineer an artist unless he be endowed with aesthetic creative ability —with aesthetic "genius" or merely "talent"; but neither will a knowledge of pure and applied physical science suffice to make him an engineer unless he have innate engineering ability—of which I shall have something to say later. The engineer cannot therefore regard aesthetics as something quite foreign to his own profession. For its welfare and ethical development humanity demands from him more than his merely mechanical utilization of the pure and applied physical sciences. This alone is no longer adequate for the satisfaction and contentment of the community—any more than the community is satisfied to-day with the old notion that the function of a successful business concern is merely to provide a fortune for its owners and a living for its employees. It may not always be easy to make, say, a gas-holder or a petrol-pump beautiful; but every product of the engineer can be so designed that at least it presents not an unpleasing appearance in itself, and one that will harmonize agreeably with the environment in which it is to be set up.

The Machine and its Operative.

From the psychology of aesthetics I pass to a problem which concerns the youngest branch of applied psychology, known as industrial (or, more accurately, as occupational) psychology, in its relation to engineering. However efficient from the mechanical standpoint, machines and implements designed for industrial use may nevertheless be unsatisfactory from the standpoint of the physical health and fatigue of the operatives and of the ease and comfort of their work. Curiously enough, this defect is less common in machines devised for the use of the general public or the highly skilled expert, for example, the motor-car, the aeroplane, and, I am informed, engineering machine-tools, with the use of which the designer is himself familiar. The engineer needs, however, to pay more consideration to the "human factor" in his design of machines for the factory, where the operatives, very often women, are semi-skilled or virtually unskilled—especially in the case of machines used in the textile industry, boot-and-shoe manufacture, box-making, tobacco-cutting, laundry work, etc.

One of the commonest defects here encountered is the unsatisfactory position or action of the pedal, the operative being forced to sit in a contorted posture to use it, or the pedal descending with rapid acceleration to a sudden stop which sends a harmful jar, with each such stoppage, through the limb and body of the operative. Another equally common defect is the wrong position of controlling levers of the machine, which may be placed needlessly distant, thus involving a fatiguing stretch of the operative's arm in order to reach them. Often, too, the appropriate height of the working-level is neglected: the feeding-end of the machine may be too high for the comfort and efficiency of the operative, necessitating the use of steps; or the delivery-end may be too low, causing needless stooping. Again, the engineer may fail to consider in his design the height to which heavy raw material will have needlessly to be lifted on to the machine by the operative, or the equally avoidable noise and vibration to which he will be subject[1]. Psycho-physiological considerations of this kind may clearly call for closer collaboration between the engineer-designer and the industrial psychologist.

The Physical Environment of the Operative.

There is not infrequently need also for such collaboration in problems that confront illuminating, heating, and ventilating engineers. For here

[1] Fuller details are to be found in Report No. 36 of the Industrial Fatigue Research Board, "On the Design of Machinery in relation to the Operator," by L. A. Legros and H. C. Weston; and in a Paper by G. H. Miles and A. Angles, "Psychology and Machine Design," Journal of the National Institute of Industrial Psychology, vol. iii, pp. 159–61 (1926).

again various factors of a psycho-physiological nature affect the success of their work. Satisfactory illumination, for example, depends not merely upon physical candle-power or lumen-output, but also upon appropriate spacing of the lamps in relation to the position of the operative, upon the absence of glare, glitter, contrast, and shadows, upon adaptation, etc.

Engineering and Management.

It is not surprising if, until quite recently, the engineer has tended to neglect the "human" aspects of his work. Not so many years ago in this country, the professional engineer was interested mainly in his own ideas, in formulas and diagrams, and in invention and design, concerned with lifeless material and mechanisms. Save in relations with his client, when, of course, clear disinterested exposition, persuasive powers, and regard for the latter's interests are of prime importance, the "human factor"—the thoughts, feelings, and actions of his fellow-beings—relatively seldom occupied his attention. Through environment and habit, and doubtless by inherited inclination, his mental "type" must have approximated to what is now (rather loosely) called "introvert" by the psychologist. The introvert is one ego-centrically "wrapped up" in his own fantasies and ideas, averse from making social contacts, self-critical, easily taking offence, and giving little immediate and outward expression to his feelings. By means of questionnaires, rating-scales, and even tests, psychologists have made frequent attempts to evaluate quantitatively the degrees and directions of introversion—or of its antithesis, extraversion—which different persons may exhibit. And some have aimed at thus giving objective proofs that certain occupational groups, especially engineers and scholars, are more introvert, less extravert, than other occupational groups, notably actors and salesmen. Accepting this distinction, one American psychologist, Dr. W. V. Bingham, has accounted for it on the ground that an "early introversion of personality leads to the development, *through disproportionate exercise*, of one's native interest in mechanism or ideas, at the expense of interest and proficiency in social contacts [1]." But a converse influence is also possible: introversion, or extraversion, may conceivably be, if not initiated, certainly fostered by an individual's innate occupational interests, with their different "drives" and talents. Or again, each may be fundamentally the effect of some common, hereditary, cause.

However this may be, the scope of the engineering profession is unquestionably far wider to-day than it has ever been before. And probably it demands, attracts, and turns out now men of more widely varying personality than formerly. Large numbers of engineers, especially in the United States, are now concerned with salesmanship, a subject to

[1] "Personality and Vocation," *Brit. J. of Psychol.*, vol. xvi, pp. 354–62 (1926).

which psychologists have devoted considerable and valuable attention. Moreover, not only the engineering apprentice, but also the engineering undergraduate, tends in later years more and more frequently now to come into touch with administrative or managerial problems under State or Municipal employment or in public utility or private engineering works; here, it has been variously estimated, the chief engineer spends one-half or even more of his time in the human problems and details of Board and Committee meetings and of administration and management. And some of the various daughter-institutions of this Institution, in their respective examinations for Associate Membership (or Graduateship), now include papers in the fundamentals of industrial administration and/or in engineering organization and management[1]. In the syllabuses of these examinations the "human factor" is definitely mentioned[2]. A large proportion of engineer apprentices taking them already hold the Higher National Certificate in mechanical or electrical engineering; and evidence of satisfactory attendance at these courses in administration, organization, and management can be endorsed on this Certificate. Courses in these subjects are to-day provided by the majority of the Technical Colleges in Great Britain, the Manchester College of Technology having been the first in this country to establish a department of industrial administration (in 1918), and carrying out post-graduate research in the application of the subject to engineering works. Some Colleges also offer one or two years' training in industrial administration to engineers and others who have been already engaged by an employer and are sent there by him for special instruction in business management.

I have read that a wall in the library of the vast building of the American National Engineering Societies bears the following legend:—"Engineering—*the art of organizing and directing men* and of controlling the forces and materials of nature for the benefit of the human race." In Germany, we were told as far back as 1929 "the teaching of management-subjects *under engineering auspices* is making rapid headway on every hand. Problems of industrial personnel are being approached through scientific research in psycho-technical institutes in the Technical Universities and with *an intimate union of engineering and psychology*, rather than as a personal art to be expounded by practical executives" (p. 231). "*Researches on such problems* are considered as properly *belonging to the Technical Universities* and requiring" the collaboration of engineers and

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[1] I gratefully acknowledge the ready help and useful information which I have here received from the secretaries of the Institutions of Civil, Mechanical, Electrical, and Production Engineers.

[2] In the syllabus prepared by the Institution of Production Engineers, this term occurs only in the preamble:—"The Council of the Institution feel that although one of the major problems of Production Engineering is that of the human factor . . . too little attention has been given to this important subject in the Curriculæ [*sic*] of Technical Schools. In certain Papers, therefore, some questions will be framed. . . ."

psychologists (p. 259)[1]. In Great Britain, however, administration and management still seldom enter into the curricula of University engineering courses, and, as I shall show, little attempt has been so far made to bring engineering and psychology into relations with one another.

Industrial Psychology and Scientific Management.

The United States was the earliest country to realize the importance of managerial problems for the modern engineer. It was first stressed in that country by the late Dr. Frederick W. Taylor, an engineer of consummate genius, but signally devoid of tact, and by many others who have since endeavoured further to develop what Taylor called "scientific management" and are themselves now, especially in America, termed "industrial" or "efficiency" engineers. These "scientific managers" did some very useful pioneer work on the subject; but almost invariably they failed to pay sufficient regard to the *human* aspects of the problems which they attacked. They tended, from their engineering training and outlook, to regard the operative as a mere machine whose efficient working was to be won through material considerations. They set about to discover what work the operative had to do and the one best and speediest way of doing it, treating him almost as if he were a "robot" mechanism, capable, as it were, of revolving at a uniform speed, in a uniform manner, throughout the hours of his working spell. Consequent on their researches in movement- (or motion-) study, they established "rigid rules for every motion", and they forced each operative into what they termed "the *one* best way of work", regardless of individual human differences that demand differences in the style of expert skill; he was thus allowed no freedom in carrying out the details of his operations. The industrial unrest and strikes produced by these and other unpsychological procedures are now well known; they persisted until, as an experienced American engineer has recently pointed out, "Management, . . . finding that their introduction was always the signal for labour troubles, finally recognized that the problem was, in its essence, psychological[2]."

Psychology and Incentives.

Such ignorance, or neglect, of psychological factors on the part of the "efficiency engineer" is again well illustrated in his attitude towards "incentives." Alike in America, in Great Britain, and elsewhere, the term came to be regarded—and indeed is still generally regarded—as

[1] "The Investigation of Engineering Education." Bulletin No. 16 of the American Society for the Promotion of Engineering Education. The italics in this paragraph are mine.

[2] Prof. Albert Watson, "The New Techniques in Supervisors and Foremen." London: McGraw-Hill Publishing Co., Ltd., 1940, p. 104.

equivalent to *financial* reward. Perhaps this arose from the adoption of the false psychology of the early economist—that in his business life man is actuated solely by the desire for monetary gain. In any case, financial reward, like movement-study, offered a subject readily amenable to measurement. And so, in the early days of "scientific management", Taylor and most of his successors busied themselves in devising many different and rival methods of payment, including "straight" and "differential" piece-rates, bonus and premium systems, "individual" and "group" piece-rate and bonus schemes, etc.

The fixation of the piece-rate, bonus, or premium depends largely upon the amount of pay that the operative may be expected to earn, and the latter involves time-study of the output that may be expected of him—again a subject easily amenable, it seemed, to exact measurement. But in reality the scientific methods of such time-study are only apparent. For after analysing the operative's movements and timing them to a small fraction of a second, the rate-setter has to add "allowances", as he calls them, for delays such as must inevitably arise owing to waiting for raw material or for inspection of the finished product, or because of occasional breakdowns of machinery or of rest-pauses voluntarily taken to dissipate fatigue, etc. But the size of these allowances can only be very roughly guessed at.

Few will deny the necessity and importance of financial incentives. But the psychologist has conclusively shown the complex causes of the demand for them and their uncertain effects. He has shown, too, that financial incentives are a dangerous, and not the most important, form of incentive. They tend, when solely stressed, to develop an atmosphere, inimical to good and loyal service, in which the employee is "out for himself", trying (as he imagines his employer also to be trying) to grab as much money from the business as he can—to *get* as much, and to *give* as little, as he can. Besides financial incentives, praise and interest in, and knowledge about, the work are at least of equal importance, and of psychologically greater value. These are all, however, in great part, "selfish" incentives. The psychologist has established the importance and effectiveness of "social" incentives. The operative is not to be regarded as a "lone hand" in his daily work, but as a member of an industrial group of fellow-workers which has its own psychological characteristics and its own codes of conduct profoundly affecting their every-day thought and act. As a member of his group, the operative demands security of employment, congenial colleagues, and, above all, sympathetic treatment both by his immediate overseers and by administration and management generally. These comprise, perhaps, the most powerful incentives to efficient work.

Two further incentives are psychologically noteworthy—the willingness of managers to consider and to reward suggestions from the operative that make for more efficient and happier work, and their willing-

ness to inquire into and to consider grievances, often unknown to them—some due to misunderstanding or rumour, but many well-justified and rectifiable. The industrial psychologist finds that the worker is influenced not so much by the actual satisfaction of his grievances as by the evinced willingness of management to investigate them. What the worker resents is indifference to the human and social outcome of mechanically planned administrative policy.

Psycho-neuroses and Occupational Life.

Such indifference cannot fail to produce general industrial unrest, due to mental worry, irritation, conflict, and maladjustment, which, if sufficiently severe, results individually in a condition of psycho-neurosis. There is no sharp line dividing the normal from the pathological features of these consequences. For successful management a broad acquaintance with this branch of medical psychology is essential.

Psychology and Time-Study.

Yet another illustration may be helpful of the contrast which I have, doubtless in too crude colours, been depicting between the " mechanistic " and the " humanistic " approaches to problems of industrial management. Whereas the industrial engineer employs time-study primarily for the purpose of rate-fixing and for the discovery of the " one best way " of the operative's movements, the industrial psychologist has seen the value of time-study when used for other purposes which do not in the same way cast on the operative any suspicion or aspersion of idleness or involve any attempt to cajole or press him to increase his output.

Time-study has proved invaluable to the psychologist in enabling him to obtain continuous records of output throughout the working spell—" work curves ", as he calls them—which reveal to him the presence of boredom, fatigue, or other undesirable features. It is also used by him to estimate the amount of the worker's " unproductive time ", so that he may study its causes. And it is used by him to detect bad methods of performing some particular part of the novice's work during his training. In each of these uses the industrial psychologist will repeat his time-study after he has introduced changes, so as to obtain definite objective evidence of the improvements which he may have effected.

By the psychologist time-study is not regarded as an *essential* accompaniment of movement-study. The latter he may be quite content to base merely upon the general principles of good movements already known to him. For him the ultimate purpose of movement-study is rather to train and instruct the novice so that he may avoid the adoption of bad habits of movement, than to force all workers into a single common

mould of movement, regardless of their individual mental and physical differences.

Psychology and Individual Differences.

In every direction the distinctive aim of applied psychology is to study and to take into practical consideration, so far as is possible, individual differences among the operatives. It is, for example, now known that some persons are exceedingly prone to accidents; in one case 50 per cent. of a large group of motor-drivers were found to be responsible for more than 80 per cent. of the occurring accidents. Accident-prone workers should obviously be removed to less dangerous situations where the risk of injury is less not only to themselves but often also to their fellow-creatures. Or, more effectively, selection tests will be introduced so as to avoid the future engagement of the accident-prone: in one case in the course of 10 years this procedure is said to have reduced the average number of accidents per operative from 1·53 to 0·27 per annum.

We now know, too, that different operatives achieve their best quality and quantity of output under different rates of machine-speed; consequently, the speed of each machine should be variable, so that it may be set to conform to the optimal working conditions of the particular operative who controls it. The irrefutable standpoint of industrial psychology is that the machine is made for the operative, not vice versa.

The psychologist has come to adopt a corresponding standpoint in regard to production-planning: in every case the plan must be fitted as far as possible to those who will have to operate it, not vice versa. Each works, therefore, needs to be studied, as a sick patient is studied, at close quarters, not from the distant, hypothetical, arm-chair. Fixed rules of planning, however useful as affording a theoretical basis, are to be avoided in actual practice, if a maximum smoothness is to be attained in the flow of work. The rigid, quasi-military regime—a standardized type of organization applicable to every individual works of the same class—so dear to the "efficiency engineer", must be leavened by a large measure of flexibility that will allow for the particular personnel who will be required to follow it, for future variations in quantity and kind of product, for periods of rush and slackness, etc.

Vocational Guidance and Selection.

But the most important study of individual differences in occupational life relates to vocational guidance and to vocational selection. The former helps the young person to choose the career for which he is best fitted; the latter helps the employer (or other person) to choose the best applicants for available vacancies. Despite the vast wastage of time and

effort and the disappointment caused by the present methods of admitting lads to the engineering profession or industry who later utterly fail to succeed therein, vocational psychology—never so important as at the present day—has not hitherto received great encouragement from the engineer. This is partly due to his natural misunderstanding of its methods. Engineers have commonly regarded psychological tests as they regard many of their own physical instruments of measurement—as only needing a mechanical routine application to provide them with accurate data. They have not taken into consideration the insistent claims of the psychologist that his tests can yield only a part of the information that is required for satisfactory guidance or selection; that the actual score at a test may be of less value than observation of the way in which it is performed; and that the assessment of qualities of character and temperament is fully as important as, if not more important than, the assessment of mental abilities. Up to now no satisfactory tests have been devised for the assessment of such traits of personality. This can be done only by observing the conduct of the applicant while performing the tests, and especially by the interviewer with the help of information received by him from others. The psychologist has, however, undoubtedly improved the interview by making its conduct more systematic and less liable to be influenced by accidental circumstances.

I cannot, of course, enter here in any detail into a description of, and into the principles underlying, the tests which have been devised for guidance and selection in regard to occupational work. But the following brief remarks with special reference to engineering are perhaps worth making. It is widely recognized now that in very varying degrees a single "general" factor of intelligence is involved in all forms of purposeful activity; and that there are also a considerable number of "group" factors, each of which is common to a particular group of activities, and of "special" factors, each of which is peculiar to a single, simple, form of activity. There is undoubtedly a group factor underlying "mechanical" and certain other abilities, which concerns the readiness to perceive the sizes, shapes, and spatial relations of objects. With this "spatial" factor certain tests that have been devised prove by mathematical analysis to be highly saturated. In the daily work of the engineer this factor is involved in his translation of two-dimensional diagrams into three-dimensional objects, and vice versa (as in the reading and making of drawings), in the pattern-maker's and moulder's ability to imagine the "inverse" of a pattern or object, etc. There is reason to believe that it is also involved in the engineer's "machine sense", as shown in his ability to realize how a machine works—how its parts fit together, how, if one of the parts is set in motion, another part will move, etc. Tests have also been devised to assess manual dexterity, hand-and-eye co-ordination, and the different abilities required in the different engineering trades; but research is still needed to establish their value more pre-

cisely. Little has yet been done to devise tests of creative imagination that are likely to have engineering value.

In one large British engineering works during the past 3 years, the present apprentice supervisor, Mr. Frank Holliday, has been taking an exceptionally active interest in the most recent developments and applications of psychological methods which are likely to be of value in the selection of his company's engineer- and trade-apprentices. He has been employing a group test [1] devised several years ago by Prof. Cyril Burt for the National Institute of Industrial Psychology in order to assess "general intelligence", and also a battery of several group tests devised by later members of its research staff to assess what is broadly termed "mechanical ability." In the course of three articles published by Mr. Holliday in *Occupational Psychology* (vols. xiv–xvi, 1940–42), he gives the following results:—Agreement between (i) the gradings based on the candidates' scores at the battery of tests, and (ii) the gradings made about fifteen months later by the Apprentice Supervisor (at that time not Mr. Holliday) occurs five times as frequently as disagreement. But when observations, made during the testing and the subsequent interview, on the candidates' methods of procedure in performing the tests, and on their traits of personality, are taken into account, "the agreement becomes of the order of 95 per cent." (p. 176).

Results almost identical with these were obtained in an investigation carried out during the previous decade by Miss E. P. Allen and Mr. Percival Smith, on behalf of the Birmingham Education Committee in a junior day Technical School and at the Central Technical College of that city. In these two institutions agreement in 74 and 80 per cent. respectively of the 108 pupils tested was found between the scores at the tests [2] and the instructors' independent grading of their pupils in respect of "apprentice ability"; and these figures were raised to 92 and 93 per cent. respectively when allowance was made for unsatisfactory temperamental traits observed at the interview or later, such as impulsiveness, unreliability, or the lack of self-confidence, perseverance, initiative, ingenuity, or co-operativeness, which the mere scores at the tests could not indicate. These tests have now been introduced as a routine measure in the selection of boys for entry into the junior Technical Schools of Birmingham. Many boys have been since followed up in their subsequent engineering (or non-engineering) careers and very satisfactory results have been obtained.

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[1] A "group test" is applicable to several persons simultaneously; an "individual test" is applied to only one person at a time.

[2] The battery used consisted of seven tests devised by the National Institute of Industrial Psychology. If not less than five of these agreed with the instructors' ranking, the divergence of the other test or two tests was ignored. Since this battery was constructed, some of the component tests have been replaced by others which later research has shown to be of greater predictive value.

For example, in a follow-up, over 2½ years, of 157 boys after leaving a junior Technical School, both the boys and their employers were asked independently and confidentially to report on the suitability of the former for their jobs under one of three grades—" very satisfactory ", " satisfactory ", and ' unsatisfactory." Of the boys (69 per cent.) found to have entered *engineering* (and allied) trades, whose suitability was reported on as " very satisfactory " both by their employers and by the boys themselves, 81 per cent., while at the junior Technical School, had obtained scores in the upper half, and only 19 per cent. in the lower half of the scores made at the test battery. On the other hand, of the boys (31 per cent.) found to have entered *non-engineering* jobs (clerical, chemical, woodwork, selling, etc.), whose suitability was also reported both by employers and boys as " very satisfactory ", only 30 per cent. had obtained scores in the upper half, and 70 per cent. in the lower half, of the scores made at the test battery. Neither the scores at the intelligence test, nor jobs at which a boy stayed for less than six months, were included in these striking results [1].

Mr. Holliday's investigations have proved unquestionably (*a*) the importance of the intelligence test in predicting success in engineering mathematics and in the more theoretical aspects of engineering, and (*b*) the equal importance of good scores at his battery of tests for success in engineering drawing and in practical work in the shops. After at least a year's knowledge of thirty engineer-apprentices, the apprentice supervisor (then not Mr. Holliday) graded them according to a five-point scale of " excellent ", " good ", " average ", " fair ", and " poor." Their scores at the battery of tests, which had been applied earlier by Mr. Holliday, were similarly graded, and this grading was compared with the apprentice supervisor's independent grading. In only six of the thirty cases was there more than one grade-point of difference. A similar comparison, made among forty-one trade apprentices, showed a corresponding difference in only five cases. For these few divergencies, no doubt temperamental unsuitability for engineering, not measured by the test scores, was largely responsible.

Mr. Holliday further concludes that a low score on the battery of tests indicates probable unsuitability for engineering, and that this prediction becomes more certain if the candidate obtains a relatively high score at the intelligence test. On the other hand, if the candidate is to succeed in his theoretical and examination work, his intelligence score must not be too low. A lad with a high score at the test battery and with a very low score at the intelligence test may, however, be excellent in his shop-work —even at such a skilled trade as tool-making.

As supplementary evidence of the promising value of vocational tests

[1] Cf. the three Reports of Research on " The Selection of Skilled Apprentices for the Engineering Trades," published by the City of Birmingham Education Committee, 1931, 1934, and 1939.

for engineering, I will only cite a statement which I have received from the chairman of another well-known engineering company—that psychological testing has proved highly useful both in revealing at the outset pupils of exceptional promise who merit special training, and in drawing deserved attention to cases of disparity between test-scores and the reports received from the school and workshop. These tests, he has also said, "give us within an hour a measure of the boy's suitability which it would take from three to six months to obtain in the works under the control of a foreman." I hope that I have said enough to indicate the remarkable progress recently made in Great Britain towards perfecting psychological methods of engineering guidance and selection. Much, of course, remains to be done. Their future progress, like that of new surgical operations, depends largely upon their actual use: "practice makes perfect."

Psychology and Training.

The conclusions which have been reached from investigations conducted in industrial training from the psychological standpoint can hardly be without interest to the engineer. The industrial psychologist's recommendation is that the tasks of workshop training and of production should be isolated, so far as possible, from one another. However unselfish the expert industrial operative may be, his need to maintain his normal output must inevitably reduce his opportunities for giving instruction. Not uncommonly he is found to yield to the temptation of using the novice for his own ends—to aid him in the simpler operations concerned with his own output, instead of training him as he might. Moreover, the experienced operative does not necessarily make a good teacher: sometimes he is innately unfitted to teach, and sometimes he has himself acquired bad habits of work. Investigation has also shown that he may not know the precise movements that he employs, and that, when he performs movements at a lower speed for demonstration purposes, they are often different from those employed by him at his normal rate of movement. The novice is apt to be distracted from learning by the noise and bustle of the shops. Unless unusually intelligent, he may fail to observe and to imitate correctly his instructor's movements. He may become bored because he is too often idle, waiting for the words of explanation that fall too rarely from his instructor's lips.

For all these reasons, the industrial psychologist advises that a specially selected teacher be appointed, qualified by his temperament, intelligence, and skill to give instruction, and that a suitable environment should be chosen for a "school", apart from that of normal production. He regards it as essential that a systematic course of instruction should be planned, comprising two sections: (*a*) technical knowledge and (*b*) actual performance of the work. A standardized method of performing the work

can easily be devised with the initial help of expert assistance. Complicated time-studies and apparatus are usually unnecessary. The general principles that have guided this standardization of performance must be explained to the novice; laboratory experiments in training in assembly work have shown that if skill is acquired merely by routine practice, it is not transferable to other operations, whereas such transfer occurs when the novice has grasped the reasons for the methods in which he has been instructed.[1]

A Concluding Problem.

I have tried to make it clear that there is ample room, indeed rather a crying need, for closer co-operation in the future between the engineer and the psychologist. This raises the question whether, how far, and if so, at what stage, the engineer should receive instruction in the principles of aesthetics and in those of industrial psychology. There are some who take the line that, in our Universities at least, the programme of teaching the engineering student is already so overloaded, and his ability to absorb knowledge has so nearly reached its upper limit, that, if any additions to the programme or other changes in it are made, they will be at the cost of sacrificing his opportunities for acquiring, during his undergraduate years, a sound grasp of the physical principles of his subject. Adherents to this school of thought have also urged that at so early a stage of his educational career the engineering student is not mature enough to appreciate instruction in the broad principles of aesthetics and industrial psychology, when he has had but scant experience in designing and is little familiar with workshop conditions. Such subjects, they urge, should find their place in " refresher " courses and be taught considerably later—in post-graduate life.

In contrast to this " stern physical drill " school of thought stands a school demanding from the Universities a far more " liberal culture." Its adherents urge that, especially at the Universities, every vocational education should be broadened, so far as possible, to become (as in every instance it can become) also of general cultural value. They ask whether it is wise that, after obtaining his school-leaving certificate, say, at the age of fifteen, the future professional engineer (or indeed any future scientist) should officially receive instruction henceforth solely in those materialistic, scientific, and technical subjects which are most intimately and directly related to the exercise of his future profession. But surely the relative values of the antagonistic principles of " rigid discipline " and of " liberal culture ", respectively underlying these two schools of thought, can be exaggerated: surely a highly civilized society demands a school in which, by mutual understanding and sympathy, a compromise has

[1] *Cf.* J. W. Cox, "Manual Skill." Cambridge: University Press, 1934. Pp. 162–177.

satisfactorily blended them. Such a compromise must be different in the case of those who are destined to become (as, in his recent remarkable Address on engineering education to this Institution[1], the President has aptly termed them) " officers in the army of civilian engineers ", and in the case of that far more numerous, but equally important, class who, instead of a broader education adapted to a wider vision, need more specialized instruction and training to become " non-commissioned officers " in this " army."

The study of the " human factor " in occupational life already figures, as I have pointed out, in the examinations established by certain Institutions of Engineers for their Associate Membership (or Graduateship), and as a subject for endorsement on the Higher National Certificate in these branches of engineering. I have, however, advanced grounds for the hope that, in the not too distant future, both syllabuses and teaching may be so revised as to give greater prominence to the psychological—as contrasted with the mechanistic—treatment of problems of administration and management. Since 1931, industrial psychology has been taught as a separate subject in but one English Technical College—that of the County of Staffordshire. Here it has been taken mainly by students of about twenty years of age who have attended evening lectures for the previous five years and have already obtained either the Higher National Certificate in Mechanical Engineering or the City and Guilds Certificate in Machine Shop Engineering. In regard to this course, I am informed by Mr. T. G. Bamford, Principal of the College, that " some of the men find it exceptionally difficult, but the more wide-awake type of mind is keenly interested in it." " As a whole," he concludes, " the class is one which has always been most successful." But the subject serves another purpose. In the first James Forrest Lecture[2], the late Dr. William Anderson, M. Inst. C.E., alluded to the " tendency among the young and inexperienced to put blind faith in formulas, forgetting that most of them are based on premises which are not accurately reproduced in practice. . . ." So, too, describing in 1936 this just-mentioned course of Lectures in industrial psychology in the " Human Factor," Mr. W. G. Emmett, who then conducted it, regards it as having " special value in introducing the student to the so-called ' inexact ' sciences ", as it dispels the notion held by " the student of physical science, at least in his early stages," that " events in Nature conform with exactness to certain simple laws " (p. 150).

I know of but one other instance where industrial psychology can be taken as a separate subject in engineering examinations, namely, in Glasgow University, where it may be chosen as a graduating subject for the B.Sc. honours degree in mechanical and electrical engineering, among

[1] Journal Inst. C.E., vol. 17 (1941–42), p. 2 (Nov. 1941).

[2] Min. Proc. Inst. C.E., vol. cxiv (Session 1892–93, part iv), p. 255.

the optional additional subjects prescribed by that University. Both in Scotland and in England, as I have already indicated, the subject finds some place in Technical Colleges in their courses on workshop organization and management when these are provided. For example, at the Royal Technical College, Glasgow—so Mr. James Smith, its Organizer, kindly informs me—an evening class in the subject is offered, attended in 1941 by sixty-three students of the average age of twenty-seven years, the syllabus of which includes such psychological topics as accident-prevention, fatigue-study, and vocational selection, besides the subjects usually comprised under "scientific management." The same college provides a course of instruction in engineering production for day students, the syllabus of which specifically mentions "industrial psychology."

It is clear that the industrial psychologist must similarly receive some training in the special problems of the engineer, if they are to collaborate satisfactorily. At present it is for the engineer to call in the applied psychologist if he thinks that he can be useful to him. It would be as absurd to wish to aim at making the engineer an industrial psychologist as to wish to make him an artist. But so often, when an outside expert's advice can be useful, it is sought too late. This mistake can be prevented only by some knowledge of what the expert can do and when he should best do it. Quite recently, the Education Committee of the Architectural Science Group of the Royal Institute of British Architects issued a report on "The Place of Science in the Architectural Curriculum." In this address I seem to have raised a closely analogous problem for the Engineer —"The Place of Aesthetics and of other fields of Psychology in the Engineering Curriculum." It is one, I am glad to understand, to which the Council of The Institution have already given close and favourable attention, not only envisaging a high educational ideal, but also taking a first and generous step towards carrying it into practical effect.

Mr. Asa Binns said that he had great pleasure in proposing the vote of thanks to Dr. Myers for the lecture which he had just given. He was certain that the audience would not only be appreciative of its instructional value, but also would appreciate the very kindly and gracious way in which the eminent Lecturer had conveyed his opinions to them. He was very sorry there was not a much larger audience, but supposed that in war time it was inevitable that the younger men were unable to be present at afternoon meetings. They would, of course, have an opportunity of reading the Lecture later. Most members present belonged to the older generation of engineers, and he was afraid they had had to acquire their little knowledge of the application of psychology to engineering in the hard school of experience—sometimes rather bitter experience. Had they had the privilege of being instructed in the kindly way in which Dr. Myers had been instructing them that afternoon, they might have been saved a good many rebuffs.

He noticed that Sir Clement Hindley, in addressing the students at Cambridge University recently, when inaugurating the new course of Lectures relating to Engineering Economics, Organization and Aesthetics [1], had ventured to give an estimate that senior engineers spent something like 75 per cent. of their time not in dealing with scientific engineering problems but in dealing with what he called "human difficulties." If so much of their time was to be taken up in managing men, and in understanding their idiosyncrasies and failures, surely it was high time that one of the James Forrest Lectures should be devoted to the subject of the application of psychology to engineering.

Dr. R. E. Stradling, in seconding the motion, said that it had been a delightful experience for him to listen to the lecture, as he was especially interested in psychology. It was the first time he had heard Dr. Myers speak, and it had been a very real inspiration to be able to hear his voice after having read many of his papers and books.

The motion was carried by acclamation.

Dr. Myers expressed his appreciation of the way in which his Lecture had been received, and observed that a Lecturer always knew whether he was being listened to with interest. It had been of great interest to him to get to know something about the engineering profession. The vote of thanks had appealed to him because of its obvious sincerity; in these days of war and of approach to old age one did like to be "bucked up" a little.

Paper No. 5276.

"Relative Merits of Wire and Bar Reinforcement in Pre-Stressed Concrete Beams."

By Rhydwyn Harding Evans, M.Sc., Ph.D., Assoc. M. Inst. C.E.

(*Ordered by the Council to be published with written discussion* [2].)

Introduction.

The principle of pre-stressing concrete members is to introduce initial stresses in the concrete of opposite sign to that produced by the dead and live loads, thereby eliminating any tensile cracks in the concrete by maintaining a fully loaded beam with compression over the whole section. For this purpose M. Freyssinet has used both high-tensile steel bars and

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[1] Journal Inst. C.E., vol. 17 (1941–42), p. 49 (Nov. 1941).

[2] Correspondence on this Paper can be accepted until the 15th May, 1942, and will be published in the Institution Journal for October 1942.

high-tensile steel wire or piano wire, the latter varying from $\frac{1}{25}$ inch to $\frac{1}{8}$ inch in diameter, with a tensile strength of from 150 tons to 175 tons per square inch, and also steel bars with no bond between the steel and concrete, the bars thus acting as tie-rods. The permissible stress in the piano-wire tension reinforcement is approximately three times that in the high-tension bar reinforcement, so that the required cross-sectional area of wire is one-third of that of the bar reinforcement. The surface-area of the wire, on the other hand, is $\sqrt{\frac{n}{3}}$ of that of the bar reinforcement for the same initial pre-stressing force, where n denotes the number of wires utilized as tension reinforcement. If wires of 0·08 inch diameter are used, the surface-area of the wire reinforcement is about four times that of the bar reinforcement, with a corresponding reduction in the bond stress for a given shear-force. These differences in the permissible stresses and dimensions of the wire and bar reinforcement, together with the possibility of eliminating the bond in bar beams, will influence the behaviour of pre-stressed concrete beams when reinforced with those types of reinforcement. No investigation seems to have been made so far to determine the relative merits of wires and bars in pre-stressed beams, and in this Paper some experimental results are presented concerning the deflexion, hysteresis loops, permanent set, and cracking loads of such beams for increasing values of initial pre-stressing force. The effect of introducing tie-rods without any bond is also considered.

Experimental Apparatus and Procedure.

The test beam was 10 inches deep, 4 inches wide, and 11 feet long, the load being applied on a span of 10 feet. The mould was constructed of two channels 10 inches by $3\frac{1}{2}$ inches by 12 feet for the sides and one channel 12 inches by $3\frac{1}{2}$ inches by 12 feet for the base. The initial prestressing (I.P.S.) force was applied by means of simple levers with their fulcrums mounted on the ends of one of the side channels, the reinforcement being connected to the short arms of the levers and a 3-ton tension coil spring to the long arms. The extension of the coil spring, namely, 10·6 inches for a load of 3 tons, was observed on a scale attached through the core to one end of the spring. The lever-ratio was 10 : 1, so that, by observing the extension of the coil spring, any I.P.S. force, up to 30 tons, could be applied, the channels of the mould being sufficiently strong to take an eccentric thrust of 33 tons. In these tests the deflexion was to be measured, and in order to ensure that no cracks appeared on the compression side of the beam immediately after releasing the I.P.S. force, it was decided to pre-stress both the tension and the compression reinforcement. Pre-stressing of only the tension or bottom reinforcement, being outside the middle third, immediately produces tensile stresses in the top

fibres of the beam which, although of no consequence in practice, would affect any recorded deflexion values. Double pre-stressing enables the reinforcement to be placed with the usual concrete cover without causing excessive tensile stresses in the top fibres after the I.P.S.-force has been released. Both levers, attached to the ends of the mould, were fitted with knife-edges, and the I.P.S.-force was divided in the required proportion between the compression and tension reinforcement by means of a subsidiary straining-block and knife-edges. In the wire beams, the compression reinforcement consisted of thirteen wires, with a total cross-sectional area of 0·0654 square inch, and the tension reinforcement of forty-four wires, with a total area of 0·221 square inch; 76 per cent. of the I.P.S.-force was applied to the bottom reinforcement and 24 per cent. to the top reinforcement. In the bar beams, the compression reinforcement consisted of one high-tensile $\frac{5}{8}$-inch diameter rod and the tension reinforcement of one high-tensile 1-inch diameter rod, the I.P.S.-force being divided between the top and bottom rods in the same ratio as for the wire beams. The wires and bar reinforcement were attached to the straining-blocks by threading the ends of the reinforcement through clear holes in the straining-blocks at each end and securing them with nuts. This method, in the case of the wires, was laborious, but it had the advantage that all wires could be easily adjusted to have the same initial tension before being pre-stressed. The I.P.S.-force was applied by tightening the tension coil spring by means of two capstans. The concrete mix used was $1 : 1\frac{1}{2} : 3$, with a slump of 4 inches, and the large number of wires in the wire beams limited the maximum size of aggregate to $\frac{1}{4}$ inch. Aluminous cement was used throughout the tests, in order to release the I.P.S.-force in a week without producing any appreciable creep in the concrete. The beams were cured under damp sacks for a week, when the I.P.S.-force was released and the beams were allowed to cure for a further period of 3 weeks in the laboratory. Two columns, 4 inches by 4 inches by 36 inches, and six 4-inch cubes, were also made from each beam mix, to enable the modulus of elasticity and the crushing strength of the concrete to be determined. When the beams were being removed from the moulds the upward deflexion due to the release of the I.P.S.-force and the loss of strain in the top and bottom steel bars were measured.

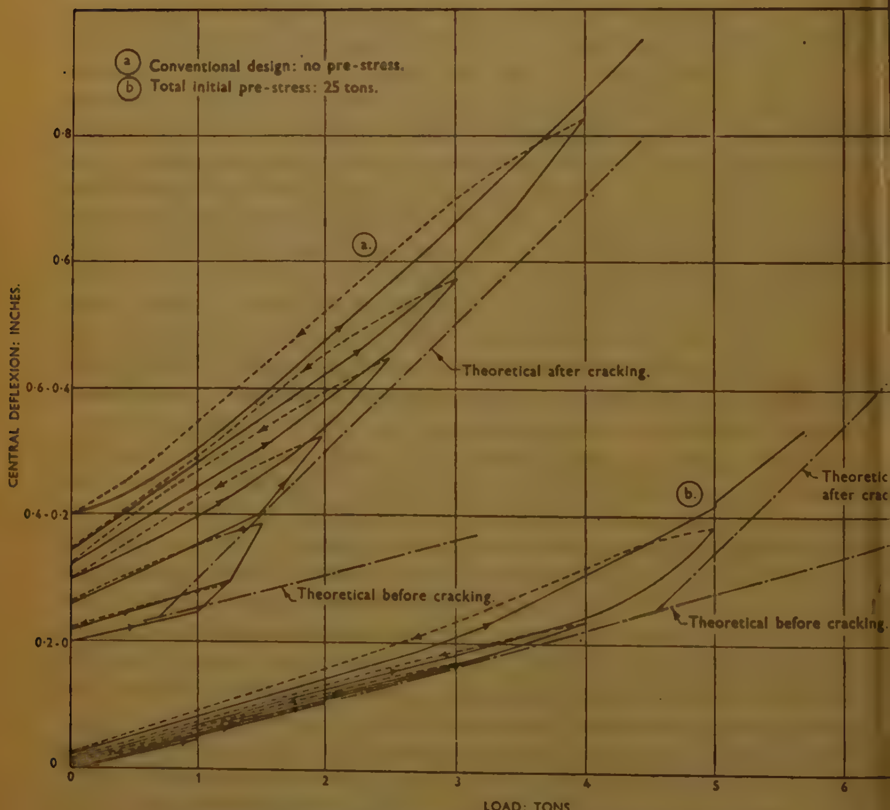
The load was applied in the form of complete cycles, with increments of $\frac{1}{4}$ ton and with the maximum load of the cycle increased at the rate of $\frac{1}{4}$ ton per cycle up to the first visible crack, and thereafter at the rate of $\frac{1}{2}$ ton per cycle up to the breaking load; the average number of readings taken per beam exceeded 600. Before being tested the beams were brushed with a thin coat of plaster of Paris, to assist in detecting the presence of cracks in the concrete by means of a magnifying glass and powerful light. The beams were examined for cracks at the maximum load of each cycle, although the first indication of any crack was given by the dropping of the lever of the testing-machine. In addition to the

central deflexion of the beam, the compressive and tensile strains in the concrete were measured by means of 8-inch extensometers, dials reading to $\frac{1}{10,000}$ inch being used for this purpose.

Experimental Results.

For a comparison of the behaviour of wire and bar beams it is sufficient to discuss typical diagrams such as those illustrated in *Figs. 1–6.* In

Fig. 1.



Concrete Beams Reinforced with High-Tension Wire.

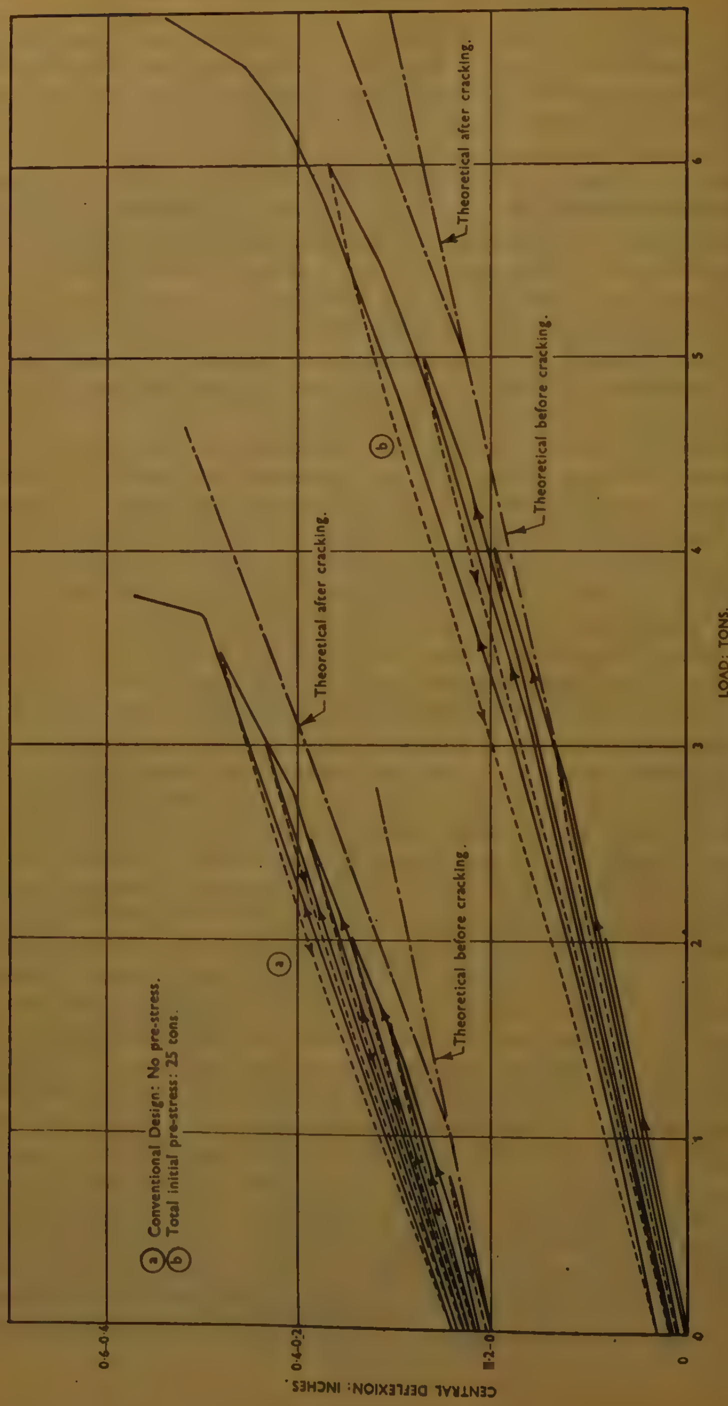
Fig. 1 the deflexions of wire beams are shown for I.P.S.-forces of 0 ton and 25 tons during the whole of the tests; a large number of readings have been omitted for the sake of clarity. The theoretical deflexions both before and after the appearance of tension cracks in the concrete are also plotted. When the concrete is intact the deflexion rate agrees with

that calculated including the concrete over the whole of the section, the rate being thus the same whether the beam is pre-stressed or otherwise. The influence of the I.P.S.-force upon the width of the hysteresis loops formed by the upward and downward branches of the deflexion cycles is demonstrated very markedly in *Fig. 1*. When there is no pre-stress the deflexion rate rises very rapidly as soon as the concrete cracks in tension, on account of the low percentage of tension reinforcement, namely, 0·6 per cent., and this rapid rise is accompanied by a large degree of permanent set, as illustrated in *Fig. 5*. The I.P.S.-force, on the other hand, not only delays the cracking load but also compels the beam to function in much the same way as in the case of plain concrete beams, in which the width of the hysteresis loops is very small. After the concrete has cracked the theoretical deflexion-rate is again the same for both conventional and pre-stressed concrete beams.

In the bar beams, in which the reinforcement is 2·4 per cent., the difference between the width of the hysteresis loops and the deflexion-rates of conventional and pre-stressed concrete beams after the concrete has cracked is not nearly so marked. This is clear when *Fig. 2* is compared with *Fig. 1*; the reason being that the percentage of tension reinforcement in the bar beams is four times that in the wire beams. The width of the hysteresis loops bears some relation to the degree of permanent set, which is greater for wide loops than for narrow loops. The set obtained in bar beams is shown in *Fig. 5* for increasing values of I.P.S.-force. Comparing wire and bar beams, it is evident that, although the set for the conventional wire beam after the concrete has cracked is many times greater than that for the conventional bar beam, the set in pre-stressed concrete beams before the concrete has cracked will vary little with the percentage of tension reinforcement. The working load of pre-stressed beams should not exceed that necessary to counteract the residual compressive pre-stress in the concrete, after allowance has been made for the weight of the beam and for the loss of some of the I.P.S.-force due to the straining, creep, and shrinkage of the concrete. Therefore it can be stated that the set in all pre-stressed concrete beams is exceedingly small, and is no more than that exhibited by plain concrete beams. When the concrete has cracked the deflexion-rate increases rapidly, in much the same way as for a conventional beam.

In order to compare the deflexions of wire and bar pre-stressed beams before and after the appearance of tension cracks, it is necessary to correct for the difference in the values of the second moment of area or moment of inertia of the section. For the bar-beams this is 1·26 and 2·71 times that for the wire beams when the concrete in tension is included and excluded respectively. Consequently, in *Fig. 4*, the deflexions of the bar beams have been multiplied by 1·26 for all loads up to the cracking load, and thereafter by 2·71, whilst the actual deflexions of the wire beams have been plotted without any modification. The conventional beam,

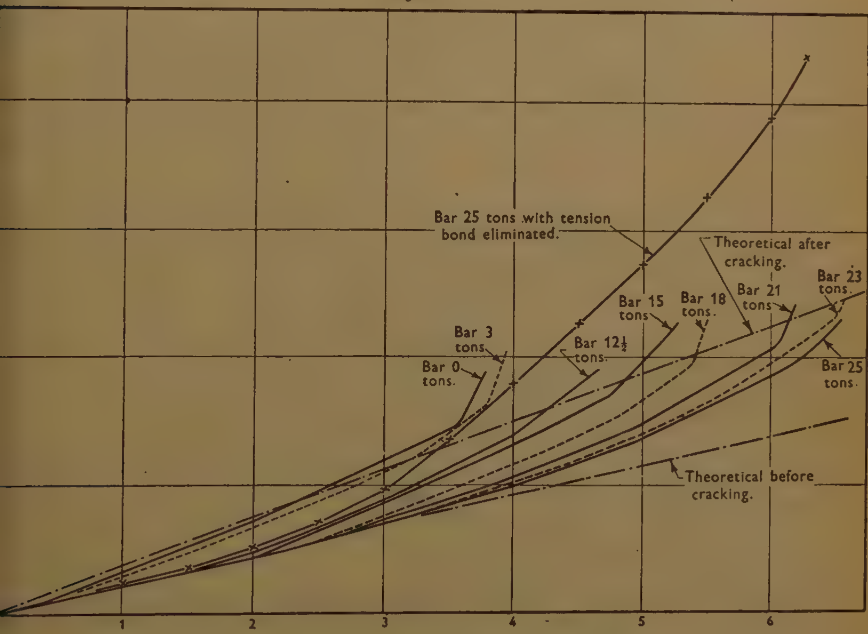
Fig. 2.



CONCRETE BEAMS REINFORCED WITH HIGH-TENSION BAR.

whether provided with bar or with wire reinforcement, should, after correcting for the difference in the moment of inertia of the section, yield identical deflexion-values when subjected to no I.P.S.-force. The proximity of the graphs marked "Bar" 0 tons and "Wire" 0 tons in *Fig. 4* shows that this is substantially true. It is also clear that, for the same load and I.P.S.- force, the deflexion of the bar beams is much greater than that of the wire beams after the concrete has cracked. This is an important difference between the behaviour of bar and wire beams, and

Fig. 3.

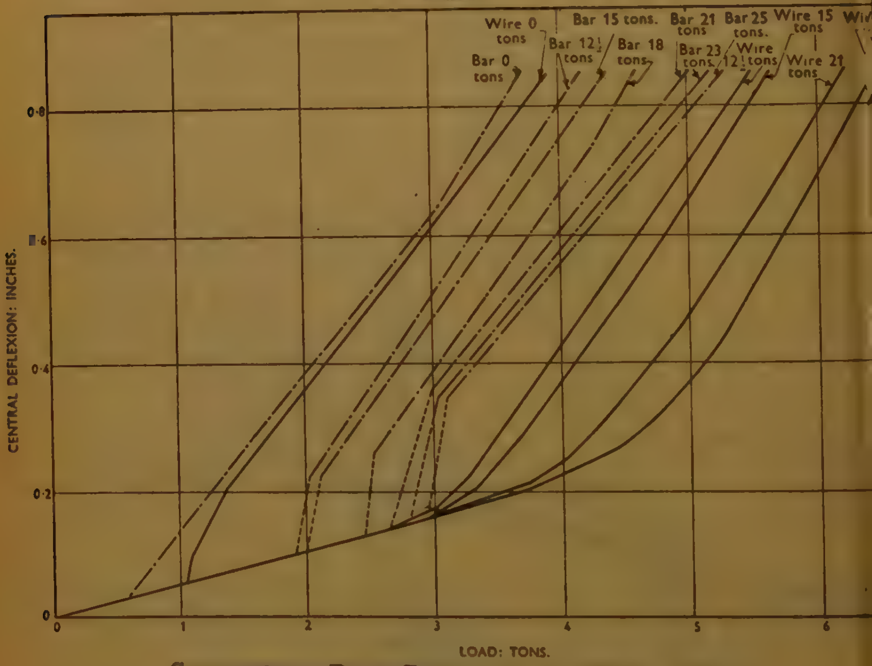


Concrete Beams Reinforced with High-Tension Bar.

it shows that the cracking load of bar beams is considerably lower than that of wire-beams when subjected to equal values of I.P.S.-force. This will be discussed in detail later. When the concrete in tension cracks in the bar beams the deflexion-rate does not change suddenly from the including tension-rate to the excluding tension-rate, as indicated in *Fig. 4*, but follows some kind of transition curve. In the case of the wire beams, however, the transition from one rate to another is more sudden, as the percentage reinforcement is only one-quarter of that in the bar beams; the transition portions of the deflexion of the bar-beams are shown dotted in *Fig. 4*, as the deflexions have been multiplied by 2·71, and these then would resemble those of the wire beams.

In practice the bond between the tension reinforcement and the concrete is often eliminated in pre-stressed beams. The influence of this upon the deflexion and the maximum concrete compressive stress is demonstrated in *Figs. 3* and *6*, for bar beams in which the I.P.S.-force was 25 tons. The tensile strains in the concrete were also measured and, when plotted, gave graphs very similar in character to those in *Figs. 3* and *6*. It is significant that, for all loads above the cracking load, the deflexion and the concrete stress are considerably higher in beams with

Fig. 4.



Comparison of Beams Reinforced with Wire and Bar.

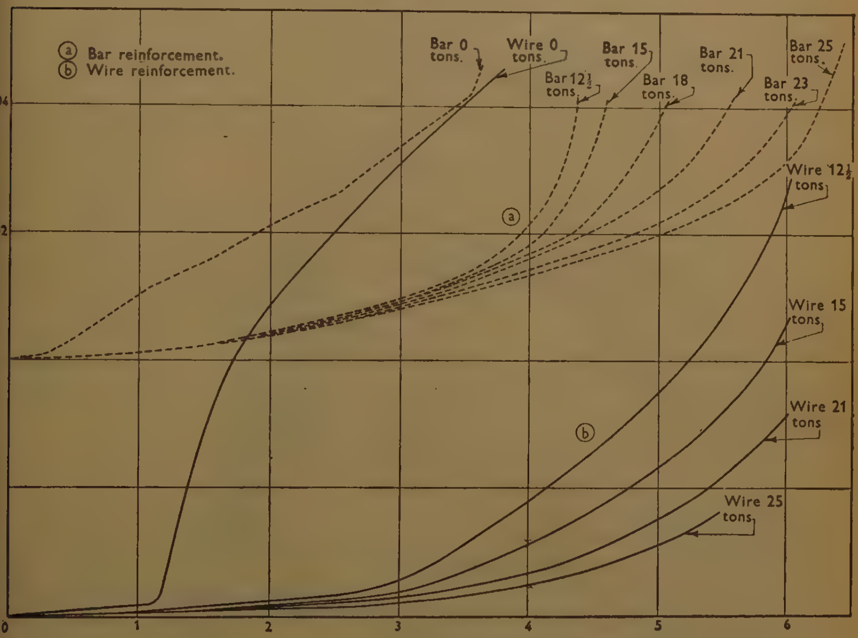
no bond than in beams with normal bond. Up to the cracking load the deflexion and stress in bond-free beams are about 50 per cent. higher than those in normal bonded beams and, near the failing load, the deflexion and stress are approximately 100 per cent. higher.

Discussion of Results.

The principal items of special interest are (*a*) the difference between the behaviour of wire and bar pre-stressed concrete beams when subjected to the same I.P.S.-force; (*b*) the influence of eliminating the bond in bar beams upon the deflexion and the concrete compressive stress.

The first item can be explained by examining the loss of I.P.S.-force due to the straining, creep, and shrinkage of the concrete. The fibre stresses due to the I.P.S.-force can be calculated by considering the stresses due to the I.P.S.-force in the top and bottom reinforcement separately, and superimposing them. When calculating the stresses due to the I.P.S.-force in the bottom reinforcement, the area of the bottom reinforcement is not included, but the equivalent area of the top reinforcement must be included. Similarly, when calculating the stresses due to

Fig. 5.

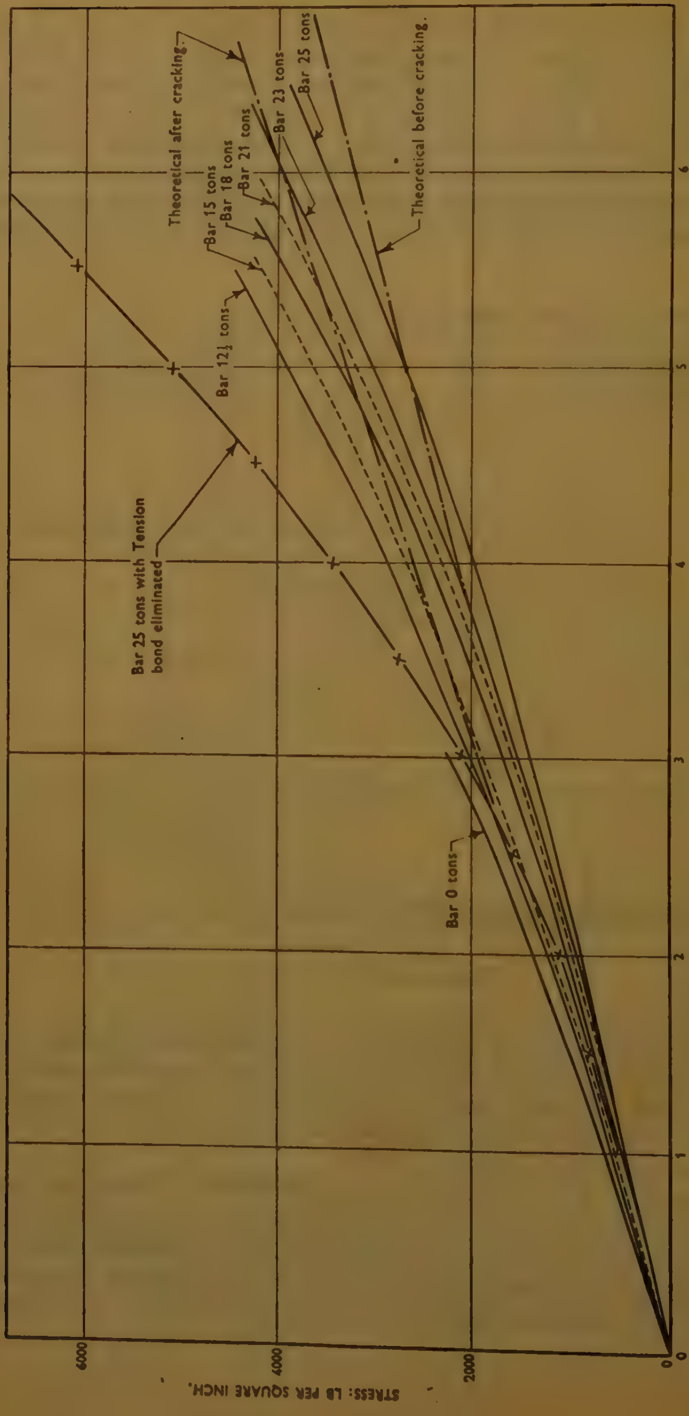


PERMANENT SET IN BEAMS.

the I.P.S.-force in the top reinforcement, the area of the top reinforcement is not included, but the equivalent area of the bottom reinforcement must be included. When determining the stresses in the beam due to any external load, the equivalent area of both the top and the bottom reinforcement must be included.

Let suffixes T and B denote the top and bottom reinforcement respectively; P_B the I.P.S.-force in lb., in the bottom reinforcement; p_B the loss, in lb., due to strain and creep, in P_B; f_B the equilibrium stress surrounding the bottom reinforcement; A_B the equivalent area of the section of the beam, excluding the bottom reinforcement; A'_B the area

Fig. 6.



COMPRESSIVE STRESS IN CONCRETE DUE TO LOADING.

of the bottom or tension reinforcement; and I_B the moment of inertia of the section of the beam excluding the bottom reinforcement.

Consider the equilibrium conditions,

$$f_B = \frac{P_B - p_B}{A_B} + \frac{(P_B - p_B)e_B^2}{I_B} + K_T \quad . \quad . \quad . \quad (1)$$

where e_B denotes the eccentricity of P_B and K_T the stress in the bottom steel due to the I.P.S.-force in top steel.

If y_B denote the distance from the centre of gravity of the bottom steel to the neutral axis, then

$$K_T = \frac{P_T - p_T}{A_T} - \frac{(P_T - p_T)}{I_T} e_T y_B.$$

Let m denote the modular ratio,

and $$p_B \text{ must} = f_B m A'_B \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Eliminating f_B in equations (1) and (2),

$$\frac{p_B}{mA'_B} = (P_B - p_B)Z_B + K_T;$$

where $$Z_B = \frac{1}{A_B} + \frac{e_B^2}{I_B};$$

or $$p_B = \frac{P_B Z_B + K_T}{\dfrac{1}{mA'_B} + Z_B} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Equation (3) shows that, for a given value of P_B, p_B is a minimum when A'_B is a minimum, that is, the loss due to strain and creep decreases with increase of steel stress.

If there is no loss of the I.P.S.-force in the top steel due to the surrounding concrete being in tension, then equation (3) will give the required loss in the bottom steel. If the concrete surrounding the top steel is in compression, there will be a loss p_T in the I.P.S.-force, P_T.

Proceeding as before, it may be shown that

$$p_T = \frac{P_T Z_T + K_B}{\dfrac{1}{mA'_T} + Z_T} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where $$Z_T = \frac{1}{A_T} + \frac{e_T^2}{I_T}$$

$$K_B = \frac{P_B - p_B}{A_B} - \frac{(P_B - p_B)e_B y_T}{I_B}$$

Substituting for K_B and K_T, and solving, the following simultaneous equations are obtained, from which p_B and p_T can be found :—

$$p_T\left(\frac{1}{mA'} + Z_T\right) + p_B Z'_B = P_T Z_T + P_B Z'_B \quad . \quad . \quad . \quad (5)$$

$$p_B\left(\frac{1}{mA'} + Z_B\right) + p_T Z'_T = P_B Z_B + P_T Z'_T \quad . \quad . \quad . \quad (6)$$

where

$$Z'_B = \frac{1}{A_B} - \frac{e_B y_T}{I_B} = \frac{K_B}{P_B - p_B}$$

$$Z'_T = \frac{1}{A_T} - \frac{e_T y_B}{I_T} = \frac{K_T}{P_T - p_T}$$

Some details of the calculations made for the loss due to straining of the concrete are given in Table I, for a total I.P.S.-force of 1 ton in the bar- and wire-beams, the modular ratio obtained from the appropriate concrete column being 8·75.

TABLE I.

Type of beam.	Z_B.	Z'_B.	Z_T.	Z'_T.	P_B: (lb.).	P_T: (lb.).	p_B: (lb.).	p_T: (lb.).	Loss in P_B: per cent.	Loss in P_T: per cent.
Bar .	0·0791	−0·0259	0·0812	−0·0203	1698	542	557	30	32·8	5·2
Wire .	0·0767	−0·0270	0·0802	−0·0254	1704	536	187	11	11·0	2·0

It is of interest to note that the loss of pre-stressing-force in the bottom bar of the bar-beams is nearly 33 per cent., and that it is sensibly three times the loss in the corresponding reinforcement of the wire-beams. This loss in the bar-beams was checked satisfactorily by fixing 8-inch extensometers to the top and bottom rods before releasing the I.P.S.-force, holes being made in the concrete to receive the points of the extensometers. The simplest method of considering the loss of I.P.S.-force due to creep is by decreasing the value of the modulus of elasticity of the concrete. The percentage-loss, due to strain and creep in the concrete, is independent of the magnitude of the I.P.S.-force, except that the modular ratio would increase slightly with increase of the I.P.S.-force. The loss due to shrinkage, on the other hand, depends only upon the concrete mix, the water/cement ratio, the types of aggregates, and the method of curing, so that the percentage-loss will decrease with increase of the initial pre-stress. In the above-mentioned beams the shrinkage, as measured off plain columns 4 inches by 4 inches by 36 inches, amounted to nearly 0·04 per cent., so that the loss in the bottom and top bars of the

bar-beams amounted to 4·08 tons and 1·59 ton respectively. In the wire-beams the loss amounted to only 1·15 ton and 0·34 ton respectively.

The influence of a change in the modular ratio upon the concrete fibre stresses, in lb. per square inch, is demonstrated in Table II, in which the stresses assuming no loss due to strain are included for comparison.

TABLE II.

Concrete fibre.	Assuming no strain-loss, $m = 8{\cdot}75$.	With strain-loss: $m = 8{\cdot}75$.	With strain-loss: $m = 14$.
Top . . .	− 8·8 (Tension)	+ 6·9	+ 8·7
Bottom . . .	+ 135·4 (Compression)	+ 87·2	+ 72·4

The load at which cracking of the concrete first occurs is very important in pre-stressed beams, and it is now clear, from the above theoretical investigation, that the cracking load of the pre-stressed bar-beams will be seriously reduced by the large percentage-loss of the I.P.S.-force. The cracking load of all beams was recorded and from a knowledge of the briquette strength of the cement mortar used it is possible to compare the recorded and theoretical cracking loads. The details are given in Table III.

TABLE III.

Beam and total I.P.S.-force: tons.	Before correcting for strain and creep.		After correcting for strain and creep.		Cracking load: tons.		
	P_B: lb.	P_T: lb.	P_B: lb.	P_T: lb.	From columns 2 and 3.	From columns 4 and 5.	Recorded from experiment.
Bar 0 .	0	0	0	0	0·75	0·75	0·65
„ 3 .	5,090	1,627	2,540	1,200	1·71	1·28	0·65
„ 12½ .	21,200	6,750	13,200	5,980	4·49	3·21	1·85
„ 15 .	25,450	8,120	16,000	7,270	4·92	3·32	2·0
„ 18 .	30,600	9,750	19,340	8,760	5·58	3·65	2·3
„ 21 .	35,600	11,370	22,700	10,280	6·28	4·07	2·5
„ 23 .	39,100	12,480	24,900	11,400	6·98	4·55	2·75
„ 25 .	42,500	13,550	27,100	12,290	7·55	4·90	2·25
Wire 0 .	0	0	0	0	0·70	0·70	0·75
„ 12½ .	18,680	9,330	16,330	8,950	2·42	2·20	2·0
„ 15 .	22,400	11,200	20,070	10,750	3·00	2·80	2·65
„ 21 .	35,900	11,270	31,000	11,170	4·79	4·30	3·95
„ 25 .	42,600	13,400	36,800	13,290	5·29	4·69	4·25

In Table III, $\frac{1}{10}$ ton has been subtracted for the dead-load bending-moment, but no correction has been made for shrinkage. The shrinkage of concrete varies with the size and shape of the test-specimen,

so that the experimental shrinkage-coefficient of 0·04 per cent. cannot be applied accurately in calculating the theoretical cracking load. The approximate loss due to shrinkage of the I.P.S.-force in the bar- and wire-beams has been given, and it is of such a magnitude as to account for the difference between the theoretical and recorded cracking loads. The ratio of cracking load to failing load is higher in all pre-stressed beams than in the conventional type of beam, the ratio increasing with increase of the I.P.S.-force. This higher ratio is a decided advantage in practice. For an I.P.S.-force of 25 tons the actual cracking load of wire-beams is almost twice that of the bar-beam, this ratio again increasing with increase of stress.

The bond stress in the wire-beams is only about one-quarter of that in the bar-beams, and there is no necessity for the provision of some mechanical bond in the form of bearing plates or hooks.

The influence of eliminating the bond between the concrete and the tension reinforcement can be determined by estimating the steel and concrete stresses. When there are no cracks in the concrete, the total strain in the tension-steel must equal the total strain in the concrete surrounding it.

Let F denote the shear force on the beam; T the tension in the tension steel; A the concrete area, including the equivalent area of the compression reinforcement only; a the area of the tension steel; k the radius of gyration of the concrete, including the equivalent area of the compression reinforcement; y the depth of tension reinforcement below the neutral axis; l the span of the beam (120 inches); and E_c and E_s the moduli of elasticity of the concrete and the steel respectively. When the beam is loaded at two points, each 46 inches from the support,

Strain between the loading-points in the concrete surrounding the tension reinforcement $= \dfrac{1}{AE_c}\left[\dfrac{y}{k^2}\left\{\dfrac{46}{120}Fl - Ty\right\} - T\right]$

Strain in the concrete at support surrounding the tension reinforcement $= \dfrac{1}{AE_c}\left[-\dfrac{Ty^2}{k^2} - T\right]$

Hence the total strain in the concrete over the whole span surrounding the tension reinforcement $= \dfrac{l}{AE_c}\left[\dfrac{y}{k^2}\left\{\dfrac{851}{3{,}600}Fl - Ty\right\} - T\right]$

Since this must equal the total strain in the steel, namely $\dfrac{Tl}{aE_s}$, the value of T can be calculated.

This expression gives a value of T which agrees satisfactorily with the measured stress, and it is appreciably higher than the value furnished by the Bernoulli-Euler theory when the concrete in tension is included. If T be known, the maximum compressive concrete-stress can be calculated; this also is higher than the value derived from the standard theory.

When the concrete has cracked in tension, the beam with the no-bonded-tension reinforcement behaves as a two-hinged arch, and this immediately results in much higher deflexion and concrete stress than in the pre-stressed beam.

Conclusions.

The experiments described were made in order to compare the relative merits of wire and bar reinforcement in pre-stressed concrete beams. The tests were carried out on beams of 10 feet span, and a series of beams were made with various values of initial pre-stressing force. The central deflexion and the concrete compressive and tensile strains were recorded. Graphs are given to show that the permanent set in all pre-stressed concrete-beams is exceedingly small and is no more than that in plain concrete-beams. It is shown that the cracking load of pre-stressed beams with bar reinforcement is considerably lower than that of pre-stressed beams with wire reinforcement, being only about one-half for an initial pre-stressing force of 25 tons. This is an important difference between the behaviour of bar and wire pre-stressed beams, as the working load should not exceed that necessary to produce tensile stresses in the concrete. The reason for this difference is explained by investigating theoretically the loss of initial pre-stressing force due to straining, creep, and shrinkage of the concrete. The percentage-loss in the bar-beams is approximately three times that in the wire-beams, the loss being a minimum when the steel stress is a maximum. The experiments show that piano-wire is a very efficient type of reinforcement in pre-stressed concrete, and that the Bernoulli-Euler theory has proved adequate in calculating the concrete fibre-stresses and the cracking-loads.

The behaviour of pre-stressed concrete beams with no bonded tension reinforcement is also investigated experimentally and theoretically. It is shown that the stresses in the tension steel and the concrete, as well as the deflexion, are considerably higher in no-bonded pre-stressed beams than in either the conventional type of concrete beam or the fully-bonded pre-stressed beam.

The Paper is accompanied by six sheets of drawings, from which the Figures in the text have been prepared.

Paper No. 5286.

"The Construction of an Arch Dam for Temporary Work."

By John Albert Posford, M.A., Assoc. M. Inst. C.E.

Many considerations are involved in the construction of a temporary dam. Usually the most important is cost, and in this the cost of demolition as well as that of construction has to be considered. Other things which will affect the design are the availability of materials and plant, the space required for the dam and for efficient working within it, the time occupied in construction and demolition, and the degree of safety and permanency desirable.

In the case described in this Paper, the problem was to construct three inlets to a pumping-station situated near the mouth of a river which had been diverted so that it flowed into the sea through a rock cutting. This river drained a catchment-area of about 14 square miles, which had a fast run-off. At the sea end of the new channel tidal gates had been installed to prevent the tide flooding up the river and submerging low-lying land farther upstream. Even so, after heavy rain these lands were often flooded by the river overflowing its banks.

The pumping-station was 60 feet upstream of the tidal gates, and at this point the channel was 18 feet wide, with vertical sides, the tops of which were about 14 feet above the bed of the river. The inlets were to be rectangular in section, 4 feet wide and 3 feet high, the inverts being as near river-bed as possible.

At low tide, with the tidal gates open, the depth of water in the channel was 3 feet. This depth rose to 7 feet as the tide came in, and the tidal gates shut. While they were shut the water in the river might rise to 12 feet above the bed before the gates reopened. As soon as they were opened again, the river water swept out through the channel with a high velocity until the depth had been reduced to about 6 feet. Thus opposite the inlets there was a considerable variation in the head of water every 12 hours, together with a strong scouring action. In the interests of owners and tenants of land bordering the river farther upstream, it was important that the river should be allowed to run out as quickly as possible after the tidal gates had opened, in order to minimize the risk of flooding after a heavy rainfall. This restricted the width of channel available for the dam and working space. Owing to war conditions, it was desirable that as little timber or steel as possible should be used, and for the same reason the work had to be carried out as rapidly as possible.

The main pump-chamber was constructed in the rock, leaving a rock wall about 5 feet thick between the excavation and the river. The inlets

were then to be tunnelled through the base of this rock wall. It was decided to allow 4 feet as the working space between the dam and the side of the rock wall; this meant that the degree of safety of the dam must be high, as failure at high water might very quickly trap workmen tunnelling for the inlet.

Any form of clay bag dam, or clay between two timber shutters, was ruled out owing to the difficulty of making a good joint with the rock bed of the river. The bed was very uneven opposite the pumping-station, and a good joint was necessary to withstand not only the head of water, but also the scour. Another reason for not using a clay dam was that it would occupy too much of the remaining width of the river after the working space had been allowed for. The use of steel sheet-piling was also excluded, owing to difficulty in obtaining supplies and to the necessity for bringing heavy plant on to the site with which to handle it.

The Author decided, therefore, to construct a concrete temporary dam which would safely deal with the conditions. A straight dam, covering the three inlets and strong enough to withstand the head of water, would have needed to be reinforced, and a rich mix of concrete would have been necessary if it was not to occupy too much of the channel. It had to be borne in mind that any dam constructed would have to be destroyed completely later on, so as to leave the channel free of obstruction. For this reason, as well as in order to conserve steel supplies, the Author decided to construct three separate semicircular dams in mass concrete.

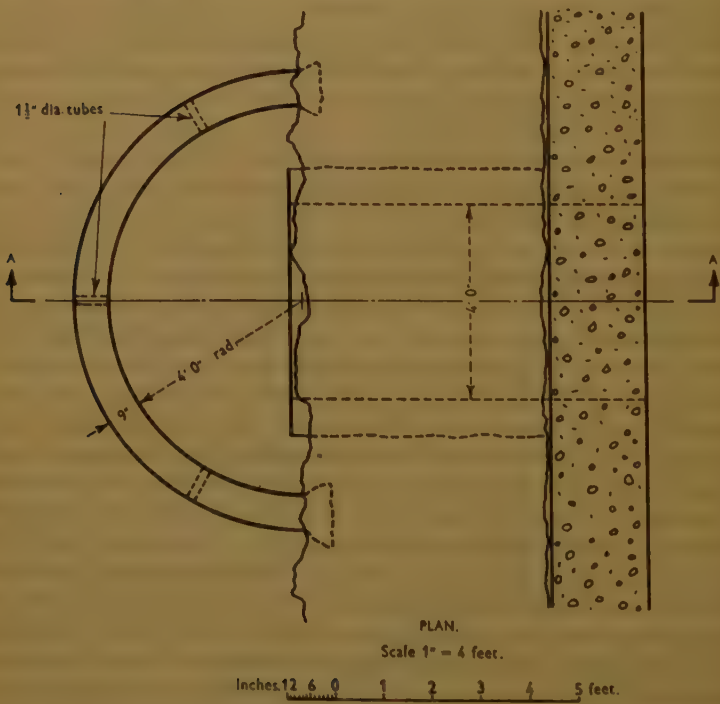
Each dam was 4 feet internal radius, and 9 inches thick; this reduced the width of the river by only 25 per cent. A stage was erected across the river about 5 feet above the bed, causing little obstruction to the flow and enabling work to proceeed 4 hours each day upon the lower part of the dams. A key was cut in the rock face wherever the dam walls ended, and was carried down as low as possible. A reasonably good bond was thus ensured for most of the height of the dam, although it was not possible to cut a key below low water. For the shuttering, 11-inch by 2-inch timber was made up into semicircular walings, the lowest being at low-water-level, and the rest at approximately 2-foot intervals above it. Tongue-and-groove boards, $\frac{5}{8}$-inch thick, were then slid down against the walings until they touched the uneven river-bed.

The success of the dam depended chiefly upon the watertightness of the joint between the concrete and the rock river-bed. Any leakage through the side joints, which, if it occurred at all, would probably appear below low water where there was no key, could be stopped more easily than leakage through the base of the dam. There were still some small gaps between the boarding and the rock bed. It was likely that the river water would scour into these gaps, and, as the tide rose, would force its way through the 9 inches of newly-placed concrete, carrying the cement with it, and would thus form a leak. Difference in head of water on either side of the dam-wall might produce the same result. It was

desirable, therefore, to equalize the level of the water on each side of the dam wall over as large a range of tide as possible. This was effected by providing in each dam three 1½-inch diameter tubes set in the wall a few inches above low water.

A stiff mix of equal proportions of sand and cement was placed through a tremie tube on the rock in the hope that, in spite of the scour, sufficient would remain to seal any fissures and make a reasonably good bond between the concrete wall and the rock. On the top of this layer of

Fig. 1.

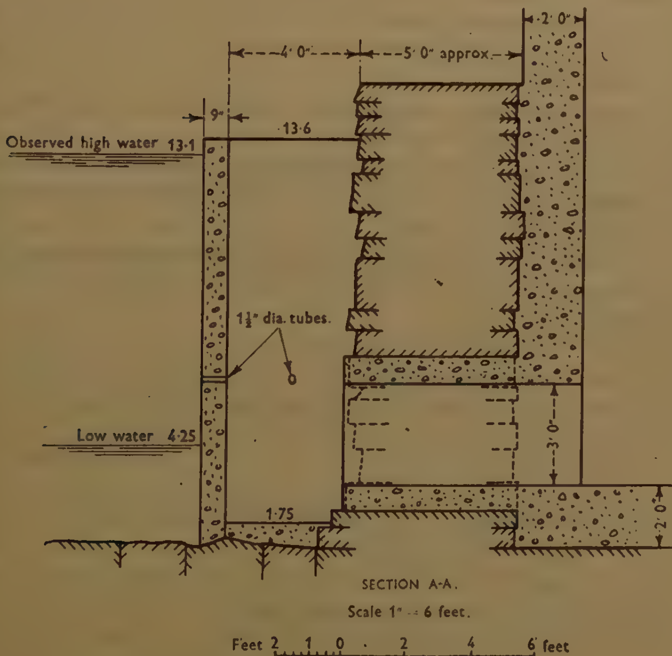


grout, 9 inches of a 4½ : 3 : 1 mix was deposited, again through the tube. As yet no punning had been done, as this would have merely mixed the dirty river water with the concrete and would have enabled it to be scoured away more easily. The dam wall was now 10 or 11 inches high, and from then on, a weak 4½ : 3 : ½ mix was used, well punned to avoid "honey-combing." All but the very lowest part of the dam walls was cast in weak concrete to facilitate cutting away when the permanent work was complete; yet owing to their arch shape they were strong enough to withstand the pressure of water at high tide. A 6-inch wall might have held, but for cheapness and speed the shuttering was only

roughly made, and variations might, and did, occur in the thickness; therefore it was thought unwise to specify an average thickness of less than 9 inches.

When the dams were pumped out with a 2-inch pump a few small leaks were disclosed, mostly caused by water seeping through fissures in the rock and welling up through the floor. The 2-inch pump was easily capable of dealing with this quantity of water; but as only one pump was available, it was necessary for at least two of the three dams to be absolutely watertight. A 6-inch concrete floor was therefore provided for each dam.

Fig. 2.



Sea-water which flowed up the river just before the tidal gates shut was liable to seep through the fissured rock into the dam. As the presence of salt water retards the setting of concrete, certain precautions were taken to exclude it. The rock floor was cleaned and cleared of small stones and debris, and the concrete wall was roughened for a height of 6 inches. Fresh water was then played into the dam through a hose-pipe; the pump was withdrawn and a greater head of fresh water was produced in the dam than that in the river outside, resulting in a flow of fresh water through the fissures. This head was maintained throughout the concreting

of the floor, as it served to carry the cement into the fissures and seal them. The concrete was deposited through a tremie tube, during low tide in the river, a stiff $4\frac{1}{2}:3:1$ mix being used. The tubes that had been left in the walls ensured an equal head of water inside and outside the dams after concreting was finished. Subsequently the tubes were plugged on the outside, and when the dams were pumped out they were found to be quite watertight at all states of the tide.

The pumping-station inlets were constructed without difficulty, and on the completion of the permanent work the floors of the dams were first cut away, and then the walls. On account of the weak concrete used in the walls they were easy to destroy, and once they had been cut down to just below low water the pumping-station could be put into operation. The lowest part of the dam walls had to be left to be destroyed during very low tides in the summer, but in the meantime caused a negligible degree of obstruction to the flow.

These three arch dams fulfilled the requirements set out in the first paragraph of this Paper. Variations on the same theme—such as providing the floor first, and then constructing the walls upon it—would enable similar dams to be constructed on foundations other than rock, thereby avoiding the use of the heavy plant associated with steel piling, as well as saving the sheet-piles themselves and the necessary timber framing. The latter point is particularly worth consideration under war-time conditions.

The Paper is accompanied by one sheet of drawings, from which the Figures in the text have been prepared, and by five photographs.

LECTURE ON

"Engineering and Architecture."

Delivered by Harry Stuart Goodhart-Rendel, Past-President R.I.B.A., at the University of Cambridge on the 24th October, 1941.

Being a Lecture in the series of Lectures on Engineering Economics, Management, and Aesthetics arranged by the Council of The Institution in conjunction with the Senate of Cambridge University.

Until about a century and a half ago, the title of this Lecture would not have been generally understood. Till then there was between engineering

and architecture no generally accepted distinction. Four centuries ago it would have been understood even less. Before the establishment of Renaissance ways of thought, there was not only no distinction generally accepted, but also there was none in fact. There was no engineering that was not architecture, and no architecture that was not engineering. The science and the art could not even be said to be fused: they were identical.

At the Renaissance, however, a new conception became prevalent of what architecture really is. Architecture came to be thought of as an intellectual and aesthetic exercise, an art that could exist almost as well on paper as in stone, concrete, and brick: an art that made construction its servant rather than its master, and that often treated its servant rather badly.

A great many writers have recognized, more or less, this essential difference between the Renaissance notion of architecture and all notions of architecture that preceded it. Many have also perceived that the Renaissance notion is still held, consciously or unconsciously, by most people to-day. I do not know that they have realized the full consequences of what they have perceived, that they have realized the radical change the Renaissance made in the very nature of the architectural art. Most of them, I think, have merely observed a change in externals, a revival of ornamental forms belonging to the past, a continuous kaleidoscopic changing of architectural fashion. In old days, they will say, one style always was universal, and constantly developing; in the last four centuries styles of all kinds have existed together at one time, and have succeeded each other not by development but by capricious choice. In fact most people think of "style" as an essential element in architecture; they think of it as having been spontaneous and involuntary before the Renaissance, and as having been conventional and considered afterwards.

Now, I maintain that we can never understand the nature of architecture in the least until we grasp that the notion signified by the word "style" is not a natural one; that before the days when "styles" were deliberately adopted there had been no such thing as "style" at all. The Pantheon is a Roman building, not a building in the Roman style; the Pennsylvania railway-station is a building in the Roman style, but is a monument of modern America.

What was the Renaissance invention in which this notion of style has its roots? It was, I think, the discovery that architectural forms and masses, composed for their pictorial effect, can often be made sufficiently convenient for use as buildings. It was the discovery that buildings of diverse character can be collected behind a uniform mask that has no detailed relation to what lies behind it. It was the destruction in architecture of the causation between reality and appearance; in other words, the practice of forcing complex buildings willy-nilly into shapes considered to be beautiful in the abstract.

We can all recognize extreme cases of this practice, such as the British

Museum, packed tidily away behind its porticoed screen, or Liberty's shop with its sham domestic casing. Both exhibit masks, not faces: the one classical, the other romantic. No Grecian would ever have dreamed of veneering a many-roomed museum with the processional portico appropriate to the rites of his religion. No Tudor builder would ever have dreamt of veneering the large departments of a modern shop with the complexity of a many-roomed manor-house. The illogicality of these examples is flagrant and unlikely to be denied; but I doubt if many people realize that the same illogicality in less degree permeates most of our modern architecture. Even the go-as-you-please little picturesque house that we build in such numbers seldom really goes as *it* pleases, throwing out a gable or sending up a chimney where it would be comfortable for it to do so. No; its gables and its chimneys generally go as the *architect* pleases, being coaxed slightly out of their natural positions to suit his preconceived notions of picturesque arrangement. Equally, if the style of the house be what is known as "modern", there will be a great deal more glass surface than is really suitable, and a good many things cantilevered over nothing that could more simply have been supported from the ground.

I believe the fact to be that architecture nowadays is usually something added to rather than something derived from construction. If this be so there is nothing unaccountable in the divorce that has taken place between the profession of the architect and that of the engineer. Nothing unaccountable, certainly, but not the less to be regretted. Let us examine some of its consequences.

The first requisite of any entirely satisfactory structure is skilful planning; the second skilful construction; the third skilful architectural expression. These requisites interlock. Skilful construction is hampered by inept planning; skilful architectural expression needs something well conceived to express. The designer of a great Roman bath establishment, of a mediaeval castle or college, was competent in all three requisites. He planned for convenience and just proportion, with constant forethought for constructional simplicity. He constructed for stability and permanence, with constant care that these qualities should be apparent. He completed his work by emphasizing its essentials and minimizing its non-essentials to the eye, using mouldings and carvings and other architectural means so that everyone might read clearly what manner of building his was.

Before the Renaissance, the planner, the constructor, and the architect were one. After the Renaissance, they may have remained one for many years, but their separate activities began to diverge. New notions sprang up of planning, of construction, and of architectural expression, which tended to become more and more independent of each other. Planning ceased to be the combination of simple units, each visible as a unit and serving its particular purpose, and became the partitioning of large architectural shells into specially appropriated compartments. It ceased to be

the putting of things together, and became the cutting of things up. The shapes chosen to be cut up were not often so fanciful as the triangular Longford Castle (symbolizing the Trinity), or the house in John Thorpe's sketch-book whose block plan was its owner's monogram ; but they were arbitrary and usually rigidly symmetrical.

Obviously over this sort of wilfulness, construction had little influence. Plan was determined largely by fancy, and construction had to do the best it could. Moreover, construction itself had to learn a lot of queer tricks to supply the demand of new fashions in expression. Horizontal architraves and lintels, longer than any procurable single stone, had to be held up somehow ; enormous cornices had to be anchored down so that they should not tip over ; heavy domes had to be gripped with metal at their springings to stop them bursting the drums on which they stood. Planning and architectural expression often became at loggerheads with the laws of gravity, and construction had to reconcile them somehow.

Here, already was divorce between engineering and architecture (if engineering may be defined as the science of construction, a sense the word now commonly bears). It did not prove to be divorce between engineer and architect, because neither the science nor the art was then complex enough for one man not to be able to master both. Sir Christopher Wren, primarily, I think, an engineer, performed prodigies of ingenuity in pitting construction against architectural conventions and allowing complete victory to neither. Others, more prudent if less gifted, designed straightforward Palladian buildings and built them in a straightforward way. The design had not much influence upon the method of building, nor the method of building upon the design ; one man might have been responsible for one, and another for the other, but it was not beyond an ordinary man's powers to undertake both.

From the general tone of my remarks so far you have probably gathered that I think the turn architecture took at the Renaissance was the wrong one. I should not like, however, to seem to disparage the many noble buildings the experiment produced. The system of planning by subdivision was bound to arrive, sooner or later, as human requirements became more complex ; and although this system encouraged a false relation between internal arrangement and external appearance, it did not necessitate it. There is something to be said for making a building a beautiful box or case, which, if it tell nothing of what is within it, nevertheless tells no lies. Yet, obviously if this is to be the process of architecture, the man who puts the box together need not collaborate very closely with the man who packs it. The two men may be one, but may equally well have separate identities as the engineer and the architect.

The words " box " or " case " suggest primarily a receptacle having some regular geometrical form ; and after the Renaissance the exteriors of buildings remained regular and geometrical until the coming of Romanticism. I hope I shall not strike you as pushing a simile to absurdity if I

remind you that a Noah's ark is also a box, and that money-boxes and fancy tins for biscuits have often taken the form of picturesquely irregular little houses. Romanticism adored the picturesque and the irregular and was thoroughly weary of classical symmetry. It might have attained the picturesque and the irregular in architecture by natural means, that is to say, by allowing the nature of buildings to decide their shape. Architects, however, had become too wilful for that. They had become accustomed to preconceiving classical forms for their buildings, and now they preconceived romantic ones. They thought of a picturesque composition; and forced what they were required to design into the shape of their thought. They stopped making their biscuit-tins cubes and began making them models of Ann Hathaway's cottage.

Now, the essential wrongness of this process lies in the fact that the picturesque is governed by no logic, by no geometry. It arises from chance; and the picturesque composition that springs unprompted into the mind of an architect is no more than his unconscious memory of some happy accident. Being an accident, it will be extremely difficult to reproduce on purpose. The world is full of buildings whose disagreeable appearance is due to their architect's muddled memory of something he has seen and sketched in his youth. To preconceive a composition like that of the British Museum is one thing; the formal merits of the design might be held to outweigh any inappropriateness there may be in it for its purpose. To preconceive a composition like that of Liberty's shop is another thing altogether; the design has no formal merits, but merely an undecided picturesqueness that is a poor return for its essential incongruity.

How far this sort of wilfulness has sent architecture from engineering could nowhere be better seen (and I imagine can still be seen) than in an astonishing railway-station I remember at Gourock, in Scotland. Here an ordinary collection of glass-roofed sheds was enclosed in red brick walls, supporting numbers of half-timbered gables complete with bargeboards and domestic windows. In producing such a monstrosity the engineer and the architect might have worked on different planets for all the converse they can have held together. Yet what an interesting time they might have had working together to produce the ideal terminus on a quay, the railway terminus on a quay that would have looked like a railway terminus on a quay, and like nothing else! The Gourock railway-station cannot have been built much more than fifty years ago, so that it is pretty certain that the engineer was one man and the architect another. Yet if it had been done entirely by an engineer or entirely by an architect, I dare say that the result might not have been any more logical. Before the complete divorce of the professions, the science and the art had long been living apart; Sir Joseph Paxton, the engineer of the Crystal Palace, was a beneficent Dr. Jekyll, Sir Joseph Paxton, the architect of Mentmore, a sinister Mr. Hyde. Although his dual personality might occasionally

unite, his two activities were almost permanently separate. Yes, the evils we suffer from to-day are of long standing.

I have now attempted to trace the steps by which architectural expression has become the uncertain art it is at present, wavering between reason and fancy. I have pointed out that before the Renaissance every major part of a building kept its identity as a unit, and that the total appearance of the building was the sum of the appearances of the units composing it. In great Roman compositions (like the baths of Caracalla) the symmetrical arrangement of the units would produce a symmetrical group; in great Gothic compositions (like any large abbey) the units, arranged according to their nature and use, would produce a group that appeared irregular. In short, the exterior appearance of any complex building followed naturally from its components until, at the Renaissance, architects hit on the idea of designing simple exteriors for buildings that were made complex by subdivision.

I have pointed out also that this practice of theirs could be justified, so long as the simple external form had in itself regularity and general suitability and did no violence to the parts it hid beneath its surface. The unjustifiable practice began when the external form was made capriciously irregular, natural irregularities being suppressed and others imposed by the whim of the architect. Of this the railway-station at Gourock is probably an extreme example. We can all probably think of a good many others; the houses in most suburbs of recent date will provide us with an almost infinite number. In the nineteenth century the average architect became, what many an architect continues to be, a fanciful, unaccountable man, having more or less skill as planner, more or less taste as decorator, more or less skill as constructor, but with no fixed plan of action, no grounding of sound architectural doctrine, no habit of logical thought.

What did the average engineer become during the same period, a period during which those engineers that were lifted by their powers above the average performed such prodigious feats? I am afraid that the average engineer became a very dull and stupid fellow indeed. (I speak here of our own country, in which engineers of reputation could get away with things like the Hungerford bridge at Charing Cross and the Ludgate Hill viaduct: other countries were less tolerant.)

I have said already that I regard Sir Christopher Wren primarily as an engineer because I think that he was more constantly interested in construction than in any of his other activities. Yet look at the range of those activities and the breadth of his field! He understood planning pre-eminently well, although in the planning of buildings he was liable to abuse his powers by contriving barren ingenuities. Few artists, whether painter, sculptor, or architect, have ever had so exact an appreciation of artistic balance and ratio as he had. In all the scientific speculations of the Royal Society he could take part without fear of rebuff. He had also a super-

lative cleverness that enabled him to find brilliant, if not always satisfactory, ways out of architectural difficulties which he often contrived himself for the fun of the thing. Compare with Sir Christopher the late Sir—but I will not name him—the defunct engineer who inflicted upon London the Hungerford bridge!

The only thing that can be said in favour of that bridge, so far as I know, is that it has no decoration applied to it by an "architectural assistant." In that it is superior to the Tower bridge, and also, as I think, to Lambeth bridge and the forthcoming Waterloo bridge, both of which have been sent as high as to the Royal Academy to be trimmed. It is honest enough, no doubt, but what a blundering thing it is! What can have happened to the science that began with the mediaeval cathedral builders, that persisted with Sir Christopher, and that declined into bathos like this?

What happened to it, I think, was that its scope was so limited as to make normal growth impossible. As I have said earlier, the three requisites of any entirely satisfactory structure are skilful planning, skilful construction, and skilful architectural expression. When the business of architecture was divided, only the second of these—skilful construction—was allotted to the engineer. Planning and architectural expression were left in the architect's hands, and were omitted from the engineer's training. The engineer still was prepared to try his hand at both, relying upon the light of Nature to guide him. Naturally, he made a terrible mess of them, which he was no longer himself well enough educated to realize. The public, however, did realize what a mess he made of architectural expression so that, on all important occasions, he was forced to submit to "architectural collaboration", which usually meant that some popular architect was called in too late for him to be able to do much good. The public realized also what a mess he made of planning, but was not convinced that any popular architect would do it much better. The engineer, therefore, was left to carry on and, by his muddled inconsequent planning, sowed the seed of many of the inconveniences and discomforts that complicate the daily life of all of us.

Discredited aesthetically, and suspected as a practical planner, the Victorian engineer had nothing left as his proper function but construction. Now, it is very difficult to construct well without the mental equipment of planning ability; and it is very disheartening to construct what you know is going to be covered up and disguised by somebody else's notion of architectural adornment. If the ordinary constructional engineering of to-day is pedestrian and conventional, it is because most of the fun has been taken out of the jobs. If the ordinary architectural expression of to-day is weak and illogical, it is because it is too little related to construction.

I suspect that the days of the self-sufficient engineer-architect are gone, never to return. M. Perret, one of the best living architects, is also an

engineer, as San Micheli and Wren were, but such men must always be exceptional. M. Perret, however, has worked with his brother as a firm, and I believe that the days of the engineer-architect firm are very soon to come. By the "engineer-architect firm" I do not necessarily mean a firm of which one member would be an engineer and another an architect, though such an association would often work well. Probably a much better firm would be one of which each member was something of both. The only reason why both functions should not be undertaken entirely by one single man is that his life would be too short, for all he would have to learn and do. Yet any specialization of function leads inevitably to limitation of outlook, and limitation of outlook is the chief malady from which the modern engineer and the modern architect alike are suffering. My ideal association would be that of a man who could properly be called an engineer-architect with one who could properly be called an architect-engineer.

The chief reason why such men are hardly ever to be found nowadays lies in the unhappy divergence of the ways in which engineer and architect are educated. The architect's education covers a field too wide for thoroughness, whereas the engineer's education is too much specialized altogether. Any approximation between their curricula could be nothing but pure gain. It has long been my cherished hope that such an approximation might take place, and the course of Lectures to which this one belongs gives me great encouragement. The ultimate goal of my hopes is the closest practicable reunion of the science and the art; but if we can produce by education good architect-engineers and good engineer-architects I think we need look no farther than that. Once produced, they and the work they do will come together in their own way.

Towards this end we can work effectively only if we face and accept unpleasant truths. In these days of war, countless admitted failures in matters of organization and administration have undermined our national superstition that Almighty God is always on the side of the man who refuses to plan. If I were to tell you the sorry tale of the failure of efforts with which I was associated as President of the Royal Institute of British Architects, of efforts to induce certain Government and other departments to meet this inevitable war with some degree of architectural preparedness, I should only be telling you what all other men in positions similar to mine would tell you as well. No suggestions were entertained, no advice was sought, no remonstrances were heeded, except in so partial a way as hardly to mitigate the blind stupidity with which, in this country, public works have so often been conducted. I am afraid that if we have refused planning in this wider sense it can surprise no one that we have refused planning also in the special sense that concerns engineers and architects. Now, however, with a Ministry of Building, and a public indignant at the way in which its money has hitherto been spent, it looks as though planning of all kinds will be allowed or even encouraged. This probability forces us

to put, and answer, the question whether planning in the past has not been refused also by architects and engineers. If we are called to supply it, how far can we do so?

Fifty years ago, the science of planning either towns or buildings was hardly understood in Great Britain at all. A few architects knew a great deal about it—Alfred Waterhouse, for example, and John Burnet and Henry Florence (the last two having studied in Paris). Most other architects, however, ignored its principles, and no engineer, on the available evidence, seems to have known that such a science existed. In consequence, the average new British building was like a hastily-packed suitcase—most things crushed in somehow, with a few sticking out, and some things forgotten altogether. Occasionally, though not often, an architect's plan was saved from utter badness by an ingenuity that, given a proper approach to the problem involved, never ought to have been necessary. An engineer's plan seems almost invariably to have been inexpert and puerile.

This is plain speaking about the past, and I propose to speak no less plainly about the present. I know that since they became two separate persons, the architect and the engineer have fallen into a rivalry in some directions that has made for sore and angry feelings when one has criticized the works of the other. I am sure that we all feel, however, that such soreness or anger springs from a rather vulgar professional outlook which honest seekers for truth must disregard. It is my hope, as I have said, that all possibilities of rivalry will some day be removed by reunion, and my belief that the first steps toward that happy end must be taken in the field of education. And first of all first steps I put the necessity of teaching young engineers to plan.

The few architects that knew how to plan fifty years ago, have now become relatively many; a fact almost entirely due, I think, to the coming of the architectural schools. In these schools a large amount of time throughout the whole of a five-year or, at any rate, a three-year course, is given to planning, which is systematized, illustrated, and continually tested by experiment. Students can learn thereby how to reduce the tangle of various requirements in which every planning problem begins to a classified and graded table of desiderata; how to decide internal lines of communication, that skeleton which rooms and corridors will flesh over; when and how to subject minor advantages to major ones; and how to discover the spacing for points of support that will crystallize the plan into orderly perfection.

In Great Britain, engineering students are still taught none of these things. I say "still", because I cannot doubt that instruction in them will come, as it has come to architectural students, who in my young days were nearly as ignorant of them as engineering students are still. Not all architectural students have profited by their instruction, but no engineering student has had any such instruction to profit by. Now, the scientific

planning of towns and buildings is not a mystery that architects should keep to themselves, but a branch of knowledge that should be as widespread as possible. Engineers must learn it, and, with architects, must convince the nation of its indispensability.

This Lecture has been written in a place where during the past two years a large collection of temporary structures has been assembled, apparently without any general design whatever. I do not imagine that the question ever arose whether a trained and competent planner should not have been employed to lay out all that ever might be required, with a view to its partial or complete realization by stages. Yet the payment of his fee and the following of his counsel would have halved, at least, the cost of what has been done, and have doubled—but no, you cannot double what does not exist!—it would have produced convenience. I should like to think that the existence of the Ministry of Building, with its indefinite programme and terms of reference, will prevent the multiplication of misdeeds like this in our post-war rebuilding. Remembering the fate of the Bressey report, I am not greatly encouraged. The shelves of Parliament are piled high with good resolutions.

When including the planning of towns as well as that of buildings within the province of my ideal architect-engineer, I have not forgotten the existence of the modern specialization called "Town-planning." "Town-planning" is a courageous attempt to correlate all the studies, historical, economic, sociological, statistical, and architectural, that concern the distribution and accommodation of population. From the standpoint of research, this correlation is of great value, but the variety of the subjects embraced suggests that education in "town-planning" is more likely to make advisers than creators. The mere technique of practical planning takes so long to acquire that it is not reasonable to expect the practical planner to divide his time between it and the processes of research, of which he needs only the results. These results the ideal architect-engineer should be competent to test; but to expect him to arrive at them himself is rather like expecting a pianist to build his own pianoforte.

When from planning I turn to construction, I turn from a subject in which the architect rules to one which is the undisputed kingdom of the engineer. Yet if I call planning "*what* to build", and engineering "*how* to build", how closely interlocked the two are seen to be! Every right decision as to *what* shall be built must be greatly influenced by *how* it is to be done. We want no more careless or fanciful designing that sets a host of unnecessary thankless problems for the constructor to solve. Furthermore, a right decision as to *how* to build is most likely to be made when the person making it is listened to if he suggest modification in *what* is proposed.

Construction *alias* Engineering, is not an exact science in which every question has one true answer and one only. If it were, there could be only

one accurate engineer in the world, because the same problem is never solved by any two engineers in exactly the same way. Constructors of genius rely no more upon their calculations than upon what you can either call their subconscious memories and perceptions or—more simply—their "hunches." Most of these "hunches" arise from nothing more than the rhythm set up in a man's mind by the constant exercise of logical thinking. Planning is, above all, logical thinking, and a mind trained by it will appear to one not so trained as miraculously intuitive. In other words, a man is likely to decide better *how* to build, if he is familiar with the fine mental processes called for in the scientific decision of *what* to build.

If British building construction of to-day is timid and conventional, as I think it mostly is, the blame for this must fall no less upon the architect than upon the engineer. Together they have failed to agitate effectively for the reform of Building Acts and by-laws that preclude many, if not most, of the experiments that ought to be made. Together they have allowed their resources to be limited by fashions, constructing at one time with solid brickwork, at another time with cast-iron stanchions and bressumers, at yet other times with framed steel, with welded steel, or with reinforced concrete, but at no time with any recourse to an out-moded material for particular things which that material still could do best. A structure battering inwards like the Eiffel tower would sustain the successively receding storeys that in a street building the angle of light often requires. I have never seen the experiment tried. Small tentative departures from rectangularity have been made lately, but there seems to be no general interest in the open question whether the pervading rectangularity of our structures is anything more than a survival from the days of universal pitched roofs. Possibly if we developed fully their implications, flat roofs might in the end turn most of our planning trapezoidal.

I suppose that what I call architectural expression is what most people who do not look below the surface consider to be architecture. I suppose that the Lecture they would expect an architect to give upon engineering and architecture would deal chiefly with how to make a compromise between a science and an art, supposed to be normally at loggerheads. I feel sure they would expect me to say what I think of the power-station at Battersea. You will have gathered already that I do not think the science and the art easily separable—much less in opposition; so I could not fulfil the first expectation even if I wished to do so.

I am, however, perfectly prepared to say of the Battersea power-station that it seems to me a specimen neither of engineering nor of architecture, but of scenic contrivance. As such I think it effective, but a very poor substitute for what might have resulted from a real grappling with the aesthetic problems its contriver has evaded. Tall furnace chimneys running down to the ground like scaffold-poles beside rectangular masses of thin-walled lightly-roofed sheds—there is material in this for a new and

noble composition, appropriate to its purpose and revealing it to the eye. Instead we have yet another variant of the popular composition rather unjustly belittled by Ruskin, that of the table turned upside down with its legs in the air. The legs are nicely shaped and serve to contain half of the chimneys, the remainder of which must be buried in the high rectangular blocks that have rather the effect of elongated pedestals to funereal columns. The sheds are screened by imposing walls as massive in appearance as if they were rock-cut; in fact the whole design is magnificently mausolean. On the opposite side of the river stands an older and less ambitious work of the same kind—a pumping-station. Here the engine-house is divided externally into two imaginary storeys of domestic architecture, the chimney taking the form of a square Italian campanile, with a fringe of roof and an iron balustrade around the top. If it is held that these buildings are both specimens of architecture, then they are specimens of the architecture of escape.

Of all the examples of aesthetic cowardice that have betrayed the mental inertia of the period which Sir Charles Petre has named our "twenty years' armistice", perhaps the most lamentable are our grand Thames bridges, constructed in one way and veneered to look as if they were constructed in another (in at least one case in a way that with the material applied would have been impossible). How well our engineers can do when not forced into fancy dress is shown by the only really good-looking bridge that London now has—excepting London bridge—I mean the new one by Chelsea Barracks. I do not applaud the heraldic decorations, but these probably were not the engineer's fault. Vauxhall bridge, of earlier date, has very little nonsense about it, but no very great positive merit.

I hope that when I condemn unreal buildings for their timidity, I shall not be misunderstood to be condemning them for their unreality. If, of two buildings exactly alike to the eye, only one were constructed in the way in which it pretended to be, it would be ridiculous to call that one beautiful and the other ugly. If our eyes are delighted by what appears to be an exquisite Grecian temple, it would be absurd to turn off our satisfaction like a tap directly one finds out that it is an American banking house. The fault in these instances lies not in the things made, but in the makers, who have doomed themselves to artistic sterility by choosing to repeat rather than to create. The problem of the power-station at Battersea contained, as almost all problems do, the germ of a new architectural effect peculiar to itself. That germ was allowed to perish, and was entombed in an extremely tasteful monument made up of familiar elements (of course with a difference—we never copy ourselves *exactly* nowadays).

Ours is an age in which new architectural developments are inevitable; they will germinate whatever we do; and our choice is between allowing them free growth and crushing them into deformity. In the eighteenth century, when the few types of buildings generally undertaken were familiar and almost standardized, it was possible for construction and architectural

expression to pursue their accustomed courses without continually renewing contact with each other. Certainly there are types of building almost standardized to-day, but few of these types do not need critical overhauling, and beyond them lies a welter of opportunist thoughtless structures, hastily called into being for new purposes and serving those purposes very ill. It is my firm conviction that order can be brought from this chaos only by the engineer and architect working hand in hand.

To say this is to postpone our salvation, since I believe the number of engineers and architects now in practice who are capable of fruitful collaboration to be small. It is to the next generation that we must look for better things, and that is what makes the education of the next generation so important. Until young engineers acquire some knowledge of the science of planning, they can hope to see nothing but the gradual monopolizing by young architects of all planning, including that which is still left at the moment for engineers to do. Until young architects concentrate their too extensive survey of construction into a thorough practical understanding of the engineer's simpler tasks, they will give trouble and not aid to the engineers they work with. Between them they have to discover the appropriate architectural expression of what they build, and to do this the young engineer must get rid of his usual notion that architecture is a fanciful addition to construction and the young architect must get rid of his usual notions that all sound construction looks like M. le Corbusier's, and that any other is out of date.

The processes of architectural expression are not very easy to define. I suppose that if they were, everybody with a logical mind could set up as an architect. Nevertheless I shall not let difficulty deter me from trying, at any rate, to approach a definition. First, I should say that architectural expression begins with the choice from among forms equally useful of the one that signifies its function to the eye. Let me explain what I mean by this at a little greater length. If you look at any collection of machines at a standstill, you will observe that some of them look as if they were going to move in exactly the way in which they can move actually, whilst others offer no such suggestion. Very frequently a machine will have several forms equally eligible for it, of which one will suggest its function and the others will not. What is true of machines is true also of the beam, the pillar, the cantilever, the strut, and what not; each of these has many possible forms, of which some are expressive and other inexpressive. Architectural expression will obviously prefer those that are expressive.

Recognition of this expressiveness is a capacity denied to nobody in some degree, but one that is much stronger and more acute in the great architect than in his less distinguished brethren. It is a capacity that can be cultivated; indeed, its cultivation should be one of the chief aims in any artistic education. It calls into play subconscious as well as conscious mental processes, and grows as experience of life accumulates. It is an important component in what the Victorians used to call creative "genius."

When we have planned well, keeping our eyes upon construction all the while; when we have constructed well, suiting our methods to the plan in which they have been foreseen; when we have chosen in all doubtful matters the course that seems to explain best to the eye what it is we have done; then shall we be a long way on the road to good architecture. We still may wreck everything, however, if we fail to obtain in our work that internal consistency, the need of which is a rule of all art.

Here, I am afraid, is another hard saying which I must try to elucidate by an example. When the British Broadcasting Corporation announces that " it is revealed in London that the streets of the metropolis are emptier of traffic than has ever previously been the case in the British capital ", we know that it means London all the time. The B.B.C. is practising what in speech and literature Mr. Fowler ironically calls " elegant variation." Now, " elegant variation " of this sort, although unfortunately it has to be tolerated in speech, can never be tolerated for a moment in the visual arts. It leads to a confusion that is the end of all expression. In architecture particularly, in any one building the same thing must always be done in the same way. In another building you can do that thing in a different way if you choose, provided that you stick to your choice throughout. But the messages of architecture are, as it were, written in code, and although there may be no fixed code, there can be no mixed code if they are to be decipherable. A " style " is a code of a sort, and though I have pointed out that the notion of style is an arbitrary one and the thing itself unnecessary, there is nothing to prevent good work from being done within its limitations. The ideal, however, would be to let every building make its own style—simple, appropriate, and unequivocal.

Having established consistency—for example, having determined in a masonry building that arches shall be used only for spans too great for lintels; that the arches shall *all* be round, or elliptical, or parabolic, or pointed, but not mixed; that all stonework surfaces horizontally exposed shall be steeply sloped (or having determined otherwise—it doesn't matter, within the bounds of common sense, what you decide, provided that you stick to it)—having established consistency, there really remains nothing more of architectural expression to be done except the application of ornament. This is a matter into which I cannot now enter. It is of all architectural processes the least important, and one with which engineering has little to do.

It is often said that the most important element of all in architectural expression is what is called " good proportion "—and you may perhaps wonder why I have not mentioned this element until now. The reason why I have not done so is that I regard " good proportion " as no matter of architectural expression, but as a certain result of proper planning and construction. " Good proportion ", after all, consists of little more than the existence of simple intelligible ratios between the various parts of the building, the due subordination of minor parts to major, and perhaps the

application of a little solid geometry in the discovery here and there of a third dimension harmonious with the two dimensions already given. When the exteriors of buildings were regarded as being independent of what lay behind them, the established proportions of the Classical Orders of architecture supplied a rule where all natural rule was lacking. When, however, the exteriors of buildings are regarded not as masks, but as faces growing on bodies, we shall expect in them not icy regularity of features but the expression of individual character. The good proportion in the face of the pugilist is not the good proportion in the face of the vestal virgin; the good proportion in the façade of an armoury is not the good proportion in the façade of a votive chapel. The simple but intelligible ratios I have postulated will arise inevitably from the adoption of a fixed unit in good planning and good construction, for without such adoption of a unit the planning and construction are unlikely to be good at all. "Good proportion" will therefore be inherent in our building before we come to consider architectural expression, and our only care need be not to spoil it.

I have now taken my imaginary engineer-architect and architect-engineer through the three processes of building design, and I hope I may have persuaded you that each of these men is needed all the way. Each must have an education differing from that which he has at present, and the provision of such education is an urgent need the post-war age must face. When France is restored to independence we shall find that much has been done there from which we can learn; the French architect-engineer has been in existence for some time, and some of his work comes very near to what the world is needing.

In the meantime we can—and, I hope shall—do much good by setting our faces against the most vicious of all results of the present maladjustment between engineer and architect; we can kill by protest, by ridicule, by any lawful means whatever, the practice of calling in an architect to veil and disguise the barbarities of the engineer. We must also stop the engineer's himself paying an architectural assistant to provide him with this protection. Engineering works must become always what they are now too seldom, things that everybody wants not to have covered up but to look at and enjoy. They were that in ancient Rome, many are that in modern France and Italy; Sweden, Switzerland, Russia, and Germany—with many other European countries—show that in the appearance of bridges, railway-stations, and other such works, our own country is the most backward of all. Of our quite recent achievements in the kind, I can think of nothing very easy to look at except the bridge I have mentioned at Chelsea, some of the London tube stations, and the Mersey tunnel (I speak of its structure and appearance, not of its planning, which seems to me all wrong on the Liverpool side). Europe challenges us to improve, and I believe that young architects and young engineers must take up the challenge together.

LECTURE ON
"Sources of Scientific Information."

Delivered by Professor ROBERT SALMON HUTTON, M.A., D.Sc., at the University of Cambridge on the 28th November, 1941.

Being a Lecture in the series of Lectures on Engineering Economics, Management, and Aesthetics arranged by the Council of The Institution in conjunction with the Senate of Cambridge University.

INTRODUCTION.

The basis of a sound University training in engineering has been ably expounded by Professor C. E. Inglis in his recent Presidential address to the Institution of Civil Engineers [1], stressing the importance of devoting this brief period of 3 years in an engineer's University training to acquiring a knowledge of the scientific principles of the subject and avoiding any temptation to technological specialization. With this conception I most heartily and humbly agree.

The duty of a University is to prepare students for the most diverse post-graduate activities and to see to it that as far as possible they shall be able to continue their own education unaided by class-room instruction, for obviously education continues far beyond one's undergraduate days.

It is just in this connexion that I think a University can do more to help to prepare us for our future careers than at present it usually undertakes. From the moment we start in any occupation, the need for access to specialized information becomes urgently apparent. It may be merely the need for some good book giving data on a branch of engineering or, perhaps more frequently, a survey of the very latest and most complete knowledge on some subject which has been progressing rapidly within recent years and upon which no book is sufficiently up to date. Or again we may need to tap information on some subject quite outside the normal interests of the engineer.

For all these purposes we should, in advance, have at least some elementary knowledge on how to use a library and what specialized library resources are available wherever our future career may ultimately land us.

Most Universities have large general libraries in addition to the more specialized ones of their Departments, whilst in large towns or cities the local libraries often provide valuable supplementary collections of

[1] Journal Inst. C.E., vol. 17 (1941–42), p. 1 (Nov. 1941).

literature. Despite these splendid opportunities, so far as I am aware, few attempts have been made in Great Britain to ensure that all University students have an adequate training in the use of libraries.

In the United States both University authorities and the general public are much more library-minded than we are in this country, although, as I shall show you shortly, great progress has been made in some directions in Britain. An example of our limitations is given by the hours of opening of the Cambridge University Library to readers; at present 39 hours per week and in pre-war days never more than 49½ hours per week, in comparison with an average of 82¾ hours per week at sixteen American Universities, including in many cases Sunday opening.

Why do we need to use scientific literature? Briefly we may consider two quite different objects:—

(1) To broaden one's outlook and keep abreast of the progress of science.

(2) To collect information on some specific subject.

The First Object.

I feel sure that Professor Inglis's philosophy of engineering education does not intend that any student of this University should limit his interests while up here to prosaic curriculum subjects, and surely no one can find it impossible to devote a few hours weekly to more general intellectual interests.

Speaking mainly to those of you who have not already enjoyed the pleasures of literary research—and the chase can indeed be fascinating and remunerative—I would suggest, as a start, a visit to your University Library or to some other good local general library.

The first thing to do is to get a broad survey of its arrangement and the facilities it offers. For instance (*a*) find out how it is catalogued, so as to be able to get any book you may want to consult or borrow; (*b*) discover whether, as is usual, new books are exposed in a special position in the main reading-room for a period before being placed on the shelves; this may give opportunities, by occasional regular visits to the Library, to survey rapidly a large number of new books; and even a brief glance at them may discover some treasure, possibly outside your main subject, which will awaken some latent interest; (*c*) note that in the Main Reading Room or elsewhere some section is reserved for so-called "Reference Books", ranging from Directories, Dictionaries, and Encyclopaedias to Bibliographies and other guides to books and information.

Another section of the library worthy of a visit from a newcomer engaged in scientific studies is the Periodicals Room. Look out for any book- or card-index to show what journals are available, both in the form of recent unbound parts and in bound volumes of past years, for it is mainly

the periodicals we need to consult for up-to-date information. Frequently "Union Lists" of periodicals are available which show what other local resources exist.

If the Library, like that at Cambridge, provides the privilege of "open access" to the shelves, you can secure the enormous advantage of being able to find, arranged under special subjects, a whole range of modern books, and thus when seeking some individual book, you are frequently led to the discovery of others hitherto undreamt of and maybe of vital importance to you.

This brief reference to the University Library does not attempt to do it justice: those who have overcome the inertia or shyness of making the first few visits, will certainly explore the library more thoroughly. To those real converts a little book by E. J. Dingwall, "How to use a Large Library", published by Bowes and Bowes, will prove helpful, as will E. A. Baker's "The Uses of Libraries", Chapters 1 and 2. In this, and in all other Libraries, do not forget that the Library staff is always able and very willing to help and:

DON'T BE AFRAID TO ASK!

A useful supplement to a slight acquaintance with the University Library would be a vacation visit to one or two London libraries. Many of you are, or will soon be, Students of the Institution of Civil Engineers. It possesses a large library and the staff are always ready to help. Perhaps it might be possible to arrange a group visit and ask for some general advice and instruction on the use of an Engineering Library. In any case, while in London visit the great Library of H.M. Patent Office in Chancery Lane, which is arranged to give an "open access" to the shelves; in fact, the only introduction you need is a gas-mask and your signature and address in the visitors' book. Here you will find many of the important periodicals and a big collection of books and monographs on various branches of science and technology.

If you wish to fulfil the first object of the use of scientific literature it is not enough to impose on yourselves the task of a few visits to the University Library. My second suggestion is that you should make a habit of scanning regularly a select small number of scientific periodicals, obviously in your case mostly of an engineering character and preferably including English, American, and, if possible, German publications (such as *Engineering* or *The Engineer*, *Mechanical Engineering* (New York), "*Zeitschrift des Vereines deutscher Ingenieure*", and the publications of the Institutions of Civil and Mechanical Engineers). In these and in the other more casually inspected periodicals, including even the daily newspaper, despite all its inaccuracies, you will come across numerous articles which will augment your knowledge on the subjects of the curriculum and stimulate your interest in directions which maybe will affect your subsequent career.

Moreover, it is mainly by such contact with periodicals that one can keep abreast of the progress of science and technology and note the general trend of development, for text-books are necessarily nearly always quite out of date. It is a good habit, even at this early stage, to adopt the practice of making notes and accurate references to such articles, either in note-books or preferably as a card-index, for a card-index is capable of unlimited expansion and rearrangement and lasts a lifetime. Even if the notes you make are merely limited to title, author, volume, page, and date of publication, you will probably find them invaluable for future use if, perhaps years afterwards, your work leads you to need just the source of information they provide. For those who are wishful of following up such methods of reading and recording, I would draw attention to a very valuable book by Dr. J. E. Holmstrom, Assoc. M. Inst. C.E, on " Records and Research in Engineering and Industrial Science " (Chapman and Hall, 15*s*. 0*d*.), especially Chapters V and VI.

The Second Object.

The second object of the use of scientific literature is to collect information on some special subject; this, although mainly perhaps a post-graduate requirement, does demand preparation and exercise during the earlier period of your career. An urgent need may arise immediately one makes contact with one's first job. To take an actual example, suppose a post is offered to you by the Anglo-Iranian Oil Company for service in Persia. Surely within a day or two, preferably even before your interview with the Company, you would want to find out all you possibly could about the following and other subjects ; the nature and manifold interests of the Company, its Directors and senior staff, the geographical, climatic, and other characteristics of Persia, and last but not least, something of the oil industry from source to finished products, none of which probably you have had any reason whatever to bother about during your University career. Such a problem is quite easy to deal with if you have acquired a facility for utilizing library resources.

Perhaps the best way to approach this subject is to proceed from the general to the particular, bearing in mind that your search for information may need to cover a much wider field than strictly engineering subjects. It is here that an acquaintance with the Reference Section of a large library proves so useful. One might, perhaps, first turn to a good encyclopaedia such as the *Encyclopaedia Britannica*, to most articles in which a list of references to books on the subject is appended. If in doubt as to the best reference books to consult, as is often the case, help is afforded by John Minto's " Reference Books ", or I. G. Mudge's " Guide to Reference Books ", and Sonnenschein's " Best Books." For engineers a book by A. D. Roberts, " Guide to Technical Literature—General and Engineering " (Grafton, London, 1939), price 15*s*. 0*d*., should be mentioned, as it gives a

good list of books on the various branches of engineering. Other "Bibliographies" will be found nearby in the Library.

Frequently in such general inquiries one may need to search beyond one's own local library, and here the "Directory" of the Association of Special Libraries and Information Bureaux (ASLIB) forms an invaluable guide to libraries and institutions, and even to private collections which are specializing in collecting literature on some individual subject.

We must not forget the large supply of Year Books and directories which often prove invaluable first-aids to getting on the track of what we seek. These are analysed in H. G. T. Cannons's "Classified Guide to 1,700 Annuals" (Grafton, 1923), or the smaller "Classified List of Annuals and Year Books" (ASLIB, 1937). Attention should also be drawn to an annual Government publication, "Guide to Current Official Statistics", which, besides being a useful reference to a large number of Government departmental reports, forms a valuable introduction to sources of information on economic literature which, of course, also represents a huge mass of publications.

Periodicals.

As I have mentioned before, the more need we have for complete and up-to-date information on any specific subject the less can we depend upon text-books, treatises, and monographs. The accounts of scientific research work and the deluge of new articles and Papers which appear in the periodicals often contain valuable matter which replaces or supplements what has been embodied in even the best books. Particularly in scientific research and in industrial practice it is imperative to keep up to date in the progress of some limited field. Here the task has now probably surpassed the capability of any individual owing to the quantity and the wide distribution of such publications.

The "World List of Scientific Periodicals" has exposed the fact that there are some 35,000 separate scientific journals; and even taking only about 15,000 of them as really important, it is estimated that about 750,000 individual scientific contributions appear every year in such journals. This "List of Scientific Periodicals" also records which of them are available in 187 Libraries in Great Britain, so that a large number of them can be found for consultation somewhere or other. Apart from this, the "Union Catalogue of Periodicals in University Libraries in the British Isles" records 25,000 additional periodicals not covered by the "World List."

Abstract Journals.

In certain subjects Abstract Journals are available, mostly sponsored by scientific or technical Societies interested in different subjects, but

even the best of them fail to survey anything like the whole field. An inquiry instituted by Dr. S. C. Bradford [1], and E. Lancaster Jones, of the Science Library, showed that 300 such abstracting and indexing journals notice 750,000 articles each year, which is the same as the total number of Papers published, but that, owing to duplication of effort, only 250,000 of the original articles are dealt with and 500,000 are missed.

At first sight one might anticipate that if one secured access to a relatively small number of periodicals and abstracting journals one should be able to cover any limited field thoroughly. Another Science Library study shows how illusory such confidence would prove. In making a survey of worth while articles on Lubrication in a large collection of scientific periodicals, these journals were arranged in three groups. Firstly those which were obviously likely to deal with the subject: in this group of twenty periodicals roughly 100 articles were found in the course of a year. The next group of 120 periodicals also yielded about 100 articles on the subject, averaging thus only about one article per year in each of such periodicals. A final group of 700 still less likely journals also yielded a further 100 articles on Lubrication, thus averaging only one article in the issues of seven years. In order, therefore, to make sure of noting all of these 300 important articles on Lubrication, we should need to survey, not twenty journals, but 840, an obviously impossible task for an individual engineer.

Even beyond these 840 periodicals there are thousands in which on rare occasions something important on the subject may occur.

A similar inquiry was made into articles on Geophysics; and the field of Electrotechnics and its abstracting was also studied. The law of this scattering has been stated as follows: If periodicals containing articles on a given subject are arranged in groups in decreasing order of the number of articles they contain on the specific subject, and if the groups are divided into a nucleus of journals more specially devoted to the subject, and into further groups containing the same number of articles as the nucleus, the number of journals in the different groups may be expressed as $1 : N : N^2 \ldots$ where the value of N is about 5 to 6.

Perhaps the position is not quite so hopeless as these figures indicate, for they deal with subjects—Lubrication and Geophysics—which are more likely to be diffused throughout a wide range of publications. So far as Chemistry is concerned, not only are publications more confined to specialist journals but also the abstracting agencies are more highly developed than in most other subjects; but even here it should be noted that whereas "British Chemical Abstracts" (Pure and Applied) survey only about 40,000 articles, the American and German abstract journals refer to 70,000 per annum.

[1] S. C. Bradford, "Sources of Information on Special Subjects." *Engineering*, Jan. 26, 1934.

In Engineering, thanks to the enterprise of the Federated American Engineering Societies, a magnificent "Engineering Index" is published, and in its annual form [1] it contains reference to about 50,000 articles appearing in 2,000 journals published in 20 different countries. This forms an invaluable guide and reference book to the past year's periodical publications.

We have not at present the ideal and complete survey which we may some day achieve; this is clearly indicated by another review by the Science Library, South Kensington, in the field of Electrical Engineering. In this subject there appear to be about 400 world-wide journals, producing about 25,000 articles a year. In the eleven abstracting and indexing publications covering the field only about two-fifths of these articles are recorded.

The Need for more Thorough Survey.

I am afraid I have rather appalled you by these statistical data. How are we to survey, cream, and utilize each year the 14,000 new books, 50–60,000 periodicals, and 750,000 articles—any of which may perchance answer some urgent and vital question? I have already said something about the initial steps for getting on the track of their existence and have emphasized that a thorough survey in most cases is beyond the unaided power of any individual. There are, fortunately, aids in course of development to which I will refer in a few moments. In the meantime let me point out the importance of such a survey and stress the duty of each one of us to help forward the provision of adequate services to supply it.

The importance of full information on any subject with which we are intimately concerned is surely not very controversial, although it is seldom sufficiently respected. If we neglect the work of others on our own subject we may spend months and years of work in trying to solve some problem, the complete answer to which is already available. Especially in industry it is important to appreciate that practice is seldom, if ever, stabilized and that if we do not progress inevitably obsolescence will overcome us, owing to the advance made by some competitors. The myth of so-called "staple" industries is well illustrated by the plight of some of our own, and in this respect Britain is particularly vulnerable owing to the fact that we were pioneers and many of our processes have tended to become stereotyped.

The duty of every individual to play at least a modest part to foster the provision of adequate surveys of the world's knowledge on his chosen

[1] A weekly card-index service is also available, by which individuals can subscribe and receive promptly references to the articles in any of some 282 engineering subjects which have appeared in the current issues of these 2,000 journals, and photoprints or translations of any selected articles are also supplied at reasonable cost. The demand for these and similar services is rapidly growing in the United States.

subject arises not only from the selfish view that in this way he will help himself to a fuller mastery of that subject, but also because his demand and that of his contemporaries will prove the best stimulus to the supply.

Of course you can reasonably ask why do we need these fifty or sixty thousand periodicals, and why those 300 and more abstract journals? Everyone would, I think, agree that there are far too many of them both. At one time I flirted with the idea of founding a new "Society for the Suppression of Redundant Periodicals", which should be a mine of wealth to the promoter; for many of the periodicals are mainly kept alive by advertisement income and I feel sure advertisers would gladly pay a fraction of what they would save, to a Society providing the necessary lethal weapon to strangle new periodicals at birth, or as soon thereafter as possible. In the meantime, unfortunately, even the least desirable journals may contain just the article we most need for the solution of our individual problem.

Some New Services already Available.

Here are some of the additional aids to access to scientific and other literature which have been developed mostly in very recent years, as we have awakened to the need for them.

The National Central Library in London acts as a clearing house for books by providing any local library, even in the smaller towns, with the loan of any of the 21½ million books contained in a large number of general and special libraries, which have agreed to co-operate in this desirable objective of making available anywhere to anyone the main literature resources of the country. Apart from the public libraries, 136 "outlier" libraries, mainly special libraries, have joined in this scheme, and from such sources about 35,000 sets of periodicals in addition to the books are available.

ASLIB has already been referred to—its main function is to serve as a clearing house for sources of information, providing its members with help in finding out which library, society, or even individual to apply to for books or information. It has held sixteen annual Conferences, attended by special librarians, information officers, and others, reports of which have been published, and by its discussions and influence has helped greatly to improve information services and their organization in Great Britain and abroad. The Association also publishes a quarterly "ASLIB Book List" of recent scientific and technical books in the English language, recommended by seventy experts. The importance of prompt indication of new books has also led to the monthly list which appears in *Nature* and to the "Technical Book Review Index" published by the American Special Libraries Association; both of the latter cover the international field, although they do not pretend to be so selective as the former.

Information Officers and Special Libraries.

In recent years a large number of societies, associations, and industrial companies have developed special libraries or information bureaux, covering individually some special subject or limited field and usually staffed by expert Information Officers. These organizations generally strive to fulfil the purpose of world-wide survey of periodicals and other sources and undoubtedly represent the nearest approach at present available to the ideal.

A new profession of Information Officers is thus developing, in which men and women with scientific education, supplemented by library training, are being employed by such organizations. The Information Officer relieves the other staff of a great deal of the searching and other preparatory work necessary to review and muster all possible data on any subject or to bring to the attention of his colleagues any new publications likely specially to concern them individually; but it must be realized that no such service can function usefully for individuals who are not themselves alive to the importance of gaining access to the information.

Once we have developed that spirit of inquisitiveness which I have suggested as desirable, such specialist information bureaux can prove invaluable to both individuals and organizations.

Further Developments Required.

Owing to the wide scatter of publications, to secure a still nearer approach to completeness calls urgently for some further co-operative effort. Obviously no one information bureau, still less one individual, can scan the whole periodical field. This next step is, however, not difficult to plan and will undoubtedly be taken as soon as an insistent demand is made sufficiently articulate. It calls for some library with access to a vast collection of periodicals and with no specialist interest in any one of them, with a staff which will index on some methodical basis—such as the Universal Decimal Classification—all the articles of worth appearing in any one of the periodicals. Sections of this index relevant to the individual abstracting journals, special libraries, and information bureaux could then be passed on to them for utilization for their individual purposes. Only in some such way can a fairly complete access to scientific information become available. The plan of such a scheme has already been put forward by Dr. Bradford and his colleagues of the Science Library[1], which library could readily be extended to undertake this work.

In conclusion, I hope no one will accuse me of trying to make any of

[1] S. C. Bradford, "The extent to which Scientific and Technical Literature is covered by present Abstracting and Indexing Periodicals." ASLIB, 14th Annual Report, 1937, pp. 59–71.

you into bookworms! Whilst too much concentration on what others have done may impede our powers of original thought, too little attention to such matters may rob us of just that stimulus to some new conception which will form a real contribution to advance.

I want to repeat that the unwieldy and vast stock of publications which provide, or may provide, just that clue to knowledge which we need, is beyond the power of an unaided individual to survey. On the other hand, unless we acquire at least an elementary and limited facility for using such sources, we may fail to develop to the full our own capacity for increasing knowledge; and unless by our individual demands we stimulate the provision of improved aids to the survey of scientific and technical information, we shall never get the better service which is undoubtedly required.

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JOINT MEETING WITH THE INSTITUTION OF MECHANICAL ENGINEERS.

16 December, 1941.

Professor C. E. INGLIS, O.B.E., M.A., LL.D., F.R.S.,
President Inst. C.E., in the Chair, supported by
Mr. WILLIAM ARTHUR STANIER, President Inst. Mech. E.

Discussion on
"Hammer-Blow in Locomotives"[1]
and on the
"Balancing of Locomotive Reciprocating Parts."[2]

The Chairman thought that all would agree that the two Papers were outstanding in their scientific interest and practical importance. Although presumably written independently, there was a remarkable similarity in the evidence they contained and the conclusions reached. Both agreed that the evil effects resulting from a lack of balance of the reciprocating parts in a modern locomotive were perhaps more hypothetical than real.

Whilst the Indian railway engineers advocated the total abolition of hammer-blow, Mr. Cox considered that some measure of over-balance should be retained in the two-cylinder locomotive.

The position of the Chairman should be one of impartial detachment, and perhaps it would be more appropriate if he maintained a masterly silence and refrained from any personal expressions of opinion. But unseemly though it might be, he did wish to make one or two observations, and perhaps that impropriety would be condoned because in engineering research the balancing of engines had been his first love, and actually his entry upon an academic career was brought about by a Fellowship thesis on that subject which he presented just 40 years ago. In those days, and ever since, he had contended that there was little or no theoretical justification for balancing the reciprocating parts of a locomotive, and that in doing so an exorbitant price in hammer-blow was being paid for something which was probably quite valueless. He had also regarded it as a clear case of a cure being very much worse than the disease. In those early

[1] Sir Harold N. Colam and Major J. D. Watson, R.E. "Hammer-Blow in Locomotives: can it not be abolished altogether?" Journal Inst. C.E., vol. 17 (1941–42), p. 197 (Jan. 1942).

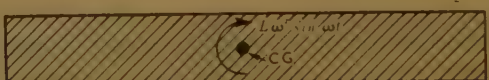
[2] E. S. Cox, "Balancing of Locomotive Reciprocating Parts." Journal Inst. C.E., vol. 17 (1941–42), p. 221 (Jan. 1942).

days it was too much to expect that practical men should pay any attention to the views of a mere academic engineer; but Sir Harold Colam happened to be one of his early students, and perhaps the instruction, "Cast thy bread upon the waters: for thou shalt find it after many days" had been functioning in that instance.

In his association with the British Bridge Stress Committee those early convictions had been confirmed in no uncertain manner by practical experiment, and it was particularly gratifying to find that that point of view was at long last receiving the consideration which its importance deserved and that the tyranny of hammer-blow was being challenged, and no longer accepted with resignation as an evil which had of necessity to be endured.

The theoretical basis for his heretical notions—because until recently to challenge the necessity of balancing the reciprocating parts of a locomotive was regarded as an act of rank heresy—would be explained by one or two lantern-slides. *Fig. 1* illustrated the effect produced by the inertia

Fig. 1.



EFFECT OF SWERVING COUPLE.

The locomotive is free to oscillate about a vertical axis through its centre of gravity;
I tons feet^2 is its moment of inertia about a vertical axis through its centre of gravity;
$L\omega^2 \sin \omega t$ tons feet is the swerving couple, ω denoting the angular velocity of the driving-wheels.

The extreme angular displacement is $\frac{Lg}{I}$ radians.

Particular case.

$L = 0{\cdot}044$ tons feet.
$I = 8{,}000$ tons feet^2.

Extreme angular deflexion is $\frac{Lg}{I} = \frac{0{\cdot}044 \times 32}{8{,}000}$

$= \frac{1}{5{,}700} = 36$ seconds of angle.

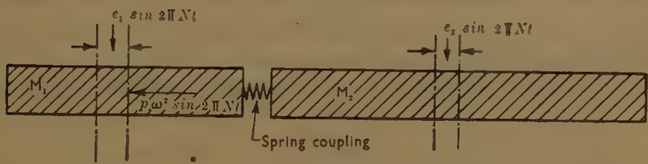
swerving couple: ω denoted the angular velocity of the driving-wheels, $L\omega^2 \sin wt$ tons feet, the primary inertia swerving couple, and I, in tons feet^2, the moment of inertia of the locomotive about a vertical axis through its centre of gravity. If the locomotive was free to pivot about that axis, the extreme angular displacement for a state of steady motion was LG/I radians.

Taking L as 0·44 tons feet and I as 8,000 tons feet^2, which were typical values for a two-cylinder locomotive, *Fig. 1* showed that the extreme

angular displacement was only 1/5700, or about 36 seconds of angle. Presumably it would be even less since frictional resistances and damping generally had been neglected. In view of the pronounced "nosing" which was inevitably caused by the coning of the wheels of a locomotive, the microscopic swerve due to inertia certainly did not seem to justify the heavy price in hammer-blow which had to be paid to effect its elimination, even to a partial extent.

The other possible evil which had to be contemplated was the state of longitudinal oscillation set up by unbalanced longitudinal inertia forces; the general nature of this effect was indicated by *Fig. 2*, which showed a

Fig. 2.



EFFECT OF LONGITUDINAL INERTIA FORCES.

$P\omega \sin 2\pi Nt$ tons is the longitudinal inertia force, where ω denotes the angular velocity of the driving-wheels.

M_1 and M_2 denote the masses, in tons, of the locomotive and train respectively;

n_0 denotes the natural frequency of relative movement of the locomotive and train;

N revolutions per second is the angular velocity of the driving-wheels;

$e_1 \sin 2\pi Nt$ and $e_2 \sin 2\pi Nt$ denote the longitudinal displacements of locomotive and train.

$$e_1 = -\frac{Pg}{M_1}\left[1 + \frac{M_2}{M_1 + M_2} \times \frac{1}{\left(\frac{N^2}{n_0^2} - 1\right)}\right] \text{ feet}$$

$$e_2 = +\frac{Pg}{M_1 + M_2} \times \frac{1}{\left(\frac{N^2}{n_0^2} - 1\right)} \text{ feet}$$

Particular case.

$P = 0{\cdot}017$ ton; $M_1 = 100$ tons; $M_2 = 200$ tons; $n_0 = 1$, $N = 5$;
$e_1 = -0{\cdot}068$ inch; $e_2 = 0{\cdot}0009$ inch.

Without the train $e_1 = -\frac{Pg}{M_1} = -0{\cdot}066$ inch.

locomotive of mass M_1 tons attached to a train of mass M_2 tons by means of a spring coupling.

The resultant longitudinal primary inertia force acting on the locomotive was $P\omega^2 \sin 2\pi Nt$ tons, where $\omega = 2\pi N$ denoted the angular velocity of the driving-wheels. Denoting by n_0 the natural frequency for

oscillations in the spring coupling, the amplitude of the oscillation of M_1 was

$$\frac{Pg}{M_1}\left[1+\frac{M_2}{M_1+M_2}\times\frac{1}{\left(\frac{N^2}{n}-1\right)}\right]\text{feet}$$

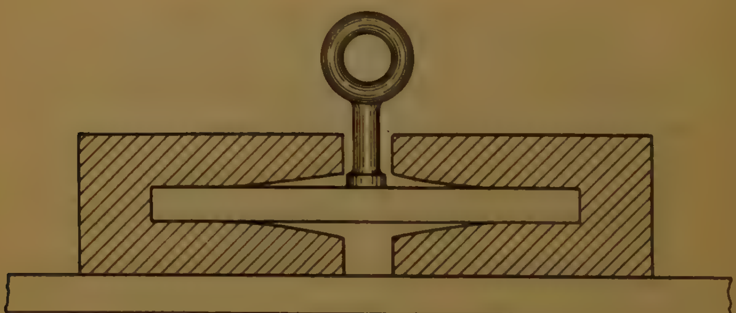
and the amplitude of the oscillation of M_2 was

$$\frac{Pg}{M_1+M_2}\times\frac{1}{\left(\frac{N^2}{n_0^2}-1\right)}\text{feet.}$$

For the case of a typical two-cylinder locomotive, in which $P = 0{\cdot}017$ tons, $M_1 = 100$ tons; $M_2 = 200$ tons; $n_0 = 1$; $N = 5$; $e_1 = 0{\cdot}068$ inch; $e_2 = 0{\cdot}0009$ inch; and at that fairly high speed of $N = 5$ those minute oscillations were certainly beneath notice.

When $N = n_0$, oscillations of a resonant character were induced, but

Fig. 3.



NON-RESONANT SPRING.

it should be noted that n_0 was small and almost certainly less than unity, and if locomotives were limited to that speed the problem of balance would have little or no importance. At such low speeds variations in tractive effort were modified by inertia to only an insignificant extent, and if at low speeds draw-bar oscillations were noticeable, he considered that they could only be attributed to the variations in the steam tractive force and not to the comparatively small inertia forces developed at those low speeds.

If draw-bar oscillations of a resonant character at low speeds had nuisance value, they could be avoided by using a draw-bar spring of the non-resonant character indicated diagrammatically in *Fig. 3*, the spring consisting of a flat bar encastered between curved cheeks. For a spring of that type the deflexion was not proportional to the load, and in conse-

quence a condition of resonance could not be established at any speed. The merits of that type of spring had hardly received the recognition they deserved and he hoped that, if they had not already done so, Mr. Stanier and other eminent locomotive engineers would give them their consideration. Having briefly stated his theoretical reasons for believing that the effects of horizontal inertia forces in producing swerve and longitudinal oscillations were quantitatively quite insignificant, he would say no more, beyond expressing his appreciation of the valuable work done by the Authors of the Papers by bringing prominently into notice a problem of such first-rate importance to railway engineers.

Major J. D. Watson and **Mr. Cox** introduced their respective Papers briefly, the latter with the aid of lantern-slides.

Mr. W. A. Stanier considered that the Authors had presented material of real interest on a problem which during the past 40 years had received a great deal of consideration from both locomotive engineers and civil engineers. He remembered as a junior, rather more than 40 years ago, riding in a horse-box behind a new engine designed by the late William Dean—a 4–4–2 tank engine for suburban work. That was a comparatively light engine, with no balance for reciprocating weights, and it was the most uncomfortable ride he had ever experienced in his life.

He thought that for many years locomotive engineers had lacked adequate means for measuring the effect of the various things they did. In reading the first Paper he had been particularly interested by the Hallade records, although personally he was not prepared to agree that those records were good ones. Reference had been made to the opinions and suggestions of the committee which visited the Madras and Southern Mahratta Railway in 1938. He was one of those who rode on some of the locomotives on that railway which had the reciprocating balance taken out of the wheels, and, at all events at 10 miles an hour, they came to the conclusion that there was distinct evidence of a fore-and-aft movement. The Authors had suggested that that limited experience made those concerned not very competent to judge. But the members of the committee were not exactly inexperienced in riding on locomotives, and, moreover, they had been riding on quite a number of engines of the same type in India. During the course of that investigation, indeed, they rode about 3,000 miles in India. One thing upon which he had commented concerned that matter of balance weight, and he had asked, "How do you know your wheels are homogenous and that the balance weight is only the proportion of reciprocating weight that you have calculated the engine requires?"

More than 20 years ago the late Mr. Churchward, of the Great Western Railway, had realized that steel castings were very erratic in their actual density, and although he had tried static balancing for locomotive balance weights, he had come to the conclusion that the only thing was a dynamic balancing machine. Mr. Cox had illustrated a machine that was practically

universal on English railways. The Great Western and other English railways might be wrong in what they put in as balance weights, but they did know that the proportion of balance weight they put in was the proportion intended. He doubted whether the railways in India knew what balance weight they actually put in. That did not prejudice in any way the importance of the subject that Sir Harold Colam and his colleagues had brought forward. It was merely an indication of how difficult it was, unless scientific methods of measurement were available, to judge fairly the effect of what was done.

Mr. Cox had rightly stated that the mass of the engine had a very considerable influence upon the effect of the amount of balancing that had been produced. The effect, as it appeared to anyone riding on the footplate, was very difficult to assess, and only impressions could be given. So far the only means found practicable in Great Britain for measuring the effect of the reciprocating balance had been the use of a dynamometer-car with a weak spring, the movement being translated. That was affected by many factors on the engine, such as the damping effect of the springs and the type of draw-bar spring between engine and tender. But with a weak spring some indication could be obtained as to whether fore-and-aft movement existed.

The London Midland and Scottish Railway had been experimenting in connexion with the balancing of reciprocating weights on locomotives. For that purpose a cine-camera had been used, and some of the results would be exhibited later in the Discussion. Mr. Cox had already mentioned the investigations on a 2–6–4 tank engine, weighing 90 tons, with no reciprocating balance, and that no detrimental effect on the wear of the boxes and parts had been detected. That was a two-cylinder engine. Supposing locomotives did not have a hammer-blow, how much extra load would the civil engineer allow on their axles ?

Mr. George Ellson said that, in view of the interesting and important questions raised by the Papers, some experiments carried out by himself in conjunction with Mr. Bulleid, of the Southern Railway, might be usefully described. They were carried out with an engine of the "Merchant Navy" Class which had been designed with no balance weights whatever. The H.15 type, from which the balance weights were specially removed, was also compared with one normally balanced, and with an electric locomotive recently designed by Mr. Raworth. The results were illustrated by lantern slides.

In considering the matter it was necessary that a proper view of all the factors should be obtained, so that a correct conclusion could be reached, and both track and locomotives should be taken into account. By "track" was meant not only the bridges, but also the far more important question of the permanent way generally, including rails, sleepers, ballast, and formation.

Firstly, there was the economic aspect, and with regard to that it

might be remarked that the railways in Great Britain, almost alone of those of the world generally, had been able to pay their way on an economic basis. In order to do that the costs which had been incurred in transporting traffic had been nicely balanced against the requirements created by the work imposed. In other words, the work which had been done on the track, and therefore the cost incurred, had been equated to present-day requirements, and probably the same remarks applied to most of the locomotives.

Although allusion had been made in one of the Papers to the "great strength of the track," it was essential to bear in mind that the strength referred to covered only requirements normally existing. In America the ordinary sleepering of the track in normal practice absorbed 83 per cent. more timber than was used in Great Britain, and rails of up to 152 lb. per yard were being used in the United States, as compared with the British standard of 95 lb., and in a few instances 100 lb. per yard.

He did not think that anyone would dispute that either the weight of rails per yard, or the number of sleepers in the track in Great Britain, was in any way excessive for the traffic which existed prior to the introduction of the super-speeds during the last few years before the war, and it would be a great mistake to think that such super-speeds could be adopted as normal practice without incurring considerably higher expenses on the track, since every dynamic influence exerted by the locomotives, detrimental to the track, increased as the square of the speed.

The principal factors in that system of inter-relationship between locomotives and the track, including in "locomotives" both steam and electric locomotives and the multiple-unit stock used on the electrified portion of the Southern Railway, were as follows:

(1) the total weight of the locomotive and the disposition and magnitude of the axle loads;
(2) the maximum speed of the locomotive;
(3) the amount of hammer-blow, if any, of the locomotive;
(4) the unsprung weight on the axles.

If hammer-blow could be abolished or materially reduced, that should most decidedly be done in heavier classes of locomotives and those running at speeds exceeding 6 revolutions per second.

There was no particular necessity to interfere with or alter locomotives which had been running at ordinary fast speeds, but in his view, with the introduction of super-speeds, the removal of hammer-blow became a necessity if economical working was to continue. The same was true of the removal of as much unsprung load as possible from axles, particularly of electric stock.

On the permanent-way side of the system of transport, it was necessary that as good a track as possible should be provided, in respect mainly of: (*a*) the alignment and level of the track; (*b*) the strength of the rails and the spacing of the sleepers; (*c*) the improvement as far as possible

of the weak spots in the track, as at points, crossings, joints, and fastenings; (*d*) the quality of the road-bed and formation.

Much had been done, including the flattening of curves wherever possible, the introduction of vertical and horizontal transition curves, the welding of rails and crossings, the improvement of the road-bed by means of improved methods of packing sleepers, the construction of drainage, and in other ways.

With regard to the problem of joints, which had always been the weakest points in the track, an investigation had been carried out some time ago on the Southern Railway under the direction of Professor Inglis, in collaboration with the then Chief Mechanical Engineer and Mr. Ellson in regard to the effect of unsprung axle loads at rail joints. The results had emphasized the desirability of the improvement of joints, especially under intensive working of multiple-unit electric trains. The type of joint which he had designed as an alternative to welding to overcome the trouble there was illustrated by a lantern slide. About 2½ miles of track had been laid with such joints, on lengths which carried fast electric trains and fast steam traffic, and the results were extremely satisfactory.

Mr. F. C. Johansen, by permission of the Director of Research of the London Midland and Scottish Railway, showed the film record to which Mr. Cox had referred in his Paper, and from which some illustrations appeared in *Figs. 3–6*[1]. He observed that the film confirmed the American experience that, with certain locomotives at very high speeds, the main driving-wheel actually lifted clear of the rail at one point in its revolution.

It should be made clear that the tests illustrated were largely qualitative. No elaborate measurements were made, and consequently the phenomena could not be completely analysed. The camera was concentrated on the main driving-wheel, that was, the intermediate coupled wheel, because at the speeds attained, that wheel bounced a good deal more violently. Once bouncing started, it tended to augment, partly because the larger impact blow bent the rail more severely, thereby increasing the upward spring load of the rail while reducing the downward load of the bearing spring. It was observed, both in a preliminary experiment on inferior track in the works as well as on standard outside track, that although there was some evidence that reduced track stiffness increased the extent to which rails were damaged, wide differences in the speed of rotation had no apparent effect upon the rate at which bouncing began. The rail under the right-hand wheels was consistently more severely damaged than that on the left-hand side. That was observed with both the ballasted and the unballasted track. Although the balancing or vertical oscillation of the wheels was the most striking feature of the film, the lateral oscillation was important relative to the present discussion. The film showed that none of the engine-frames suffered appreciable vertical isolation, whereas the lateral oscillation of the trailing

[1] Journal Inst. C.E. vol. 17 (1941–42), facing pp. 228 and 229. (Jan. 1942).

end of the engine was marked in the case of the 30-per cent. balanced engine.

The visual evidence suggested that the axis of the lateral oscillation was the pivot of the leading bogie truck. That was reasonable firstly because the downward load, amounting to 17 tons 9 cwt., of the bogie wheels on the rails was not subject to hammer-blow, and secondly because the centering control springs of the bogie were initially compressed to the extent of 2 tons. With regard to the amplitude of lateral oscillation observed, it was worth noting that with each engine flange burns occurred on the inner side of both rails. That was the case even with the $66\frac{2}{3}$-per cent. balanced engine at 103 miles per hour slipping speed. In the case of the 30-per cent. balanced engine, the greater reciprocating out of balance must have resulted in greater transverse accelerations and flange impacts, so that the lateral movements of the engine frame and body were of greater amplitude and, in consequence, more remarkable.

Mr. J. C. L. Train observed that some years ago, when he accompanied the late Sir Nigel Gresley on some trial runs preparatory to the running of the "Silver Jubilee" engine, he had remarked that he did not see how a continuously high speed could be maintained with a steam locomotive, having regard to the heavy reciprocating parts as opposed to the mechanism of an internal-combustion engine, an electric motor, or a steam-turbine. Sir Nigel was quite confident, however, and, as all knew, he and other Mechanical Engineers had succeeded in achieving extraordinary records of reliability with steam-locomotives at very high speeds. Mr. Train was glad that Mr. Cox had drawn attention to the low weights attained in the case of reciprocating parts in London and North Eastern Railway locomotives, as Sir Nigel Gresley had emphasized the importance of that.

Despite the fact that Mr. Train's ideas, as expressed to Sir Nigel Gresley, had been refuted, in practice he still considered that as a steam-locomotive was at a disadvantage in comparison with other forms of motive power by reason of its reciprocating parts, and that, as speeds after the war would, he imagined, have to be much nearer 8 revolutions per second than 5, it was essential that they nullify the effect of these reciprocating parts and at the same time avoid hammer-blow.

Mr. Cox had discussed various methods of balancing and had left it to the Bridge Engineer to decide which was the best from his point of view. In Mr. Train's view the interest of both the Bridge Engineer and the Permanent Way Engineer was the same. In the case of bridges it was rather the component parts, such as rail-bearers, which suffered most from hammer-blow, so that it was not so much a question of the whole engine hammer-blow on a long span as of the individual wheel hammer-blow on component parts. That applied equally to the case of rails, and although it was a somewhat doubtful calculation he believed that Mechanical Engineers would be astonished at the stresses which could be set up in rails under modern conditions.

Many bridges in Great Britain were of considerable age and the amount of hammer-blow was, and would become to an even greater extent, a deciding factor in the permissions granted by the Civil Engineers for engines to circulate.

In the first Paper reference had been made to a bridge deflexion measuring device which was satisfactory. Mr. Train would like to have details of that.

He agreed that the influence of rail joints upon impact on bridges was considerable and that the Civil Engineer's task was to eliminate, so far as he could, that source of trouble.

He was not prepared to assert that figures available had established that high-speed running had been responsible for an increase in fractures and defects, but there was certainly suspicion that that was so, and if hammer-blow was to be increased there would, in his opinion, be a definite increase in the number of fractures and defects.

Between 1935 and 1937 the Paris–Lyons–Mediterranean Railway had carried out tests with "Pacific" and "Atlantic" locomotives. With the former, which corresponded very nearly with British locomotives, some fairly startling results were obtained by means of a specially-fitted locomotive and recording-vans attached, in which he had been privileged to travel over considerable distances. Side pressures on the straight were recorded up to 6·3 tons (due presumably to "nosing"), and on a 35-chain curve a side pressure on the leading coupled wheels of 13·5 tons was recorded. Those actually-recorded flange pressures appeared to agree quite closely with theory as calculated by the Porter method. If a static wheel load of 11 tons were taken, then, according to Nadal's formula, the safety margin as regards climbing in the case of the curve had already been passed, and he would like to ask the Authors whether they had been able to relate hammer-blow to wheel load as likely to affect the question of climbing. Everyone knew cases of climbing, whether they had led to final derailment or not, and he suggested that hammer-blow in a negative sense might have quite a serious influence, particularly bearing in mind the experiment carried out on the London Midland and Scottish Railway referred to by Mr. Cox.

Mr. Train concluded that balancing of reciprocating parts was an undesirable practice from the Civil Engineer's point of view and that the Mechanical Engineer's best way of dispensing with the balancing of reciprocating parts was to employ multi-cylinder engines which were to a great extent naturally balanced. An excellent specification for a locomotive would be that it should have no greater hammer-blow at 8 revolutions per second than at, say, 5 revolutions per second.

Mr. O. V. S. Bulleid observed that, so far as reciprocating balance weight abolition was concerned, he seemed to have struck a rather fortunate line in locomotive design, and, as Mr. Ellson had demonstrated, they could see no ill effects from the absence of reciprocating balance if they took

reasonable precautions in other directions. The absence of reciprocating balance weights was very interesting from the locomotive point of view, for on the engine which had been mentioned 1,377 lb. of dead weight had been saved, and that, if one was designing locomotives to the maximum weight allowed, was very important.

Any ill effects of such lack of balance had been minimized by using a shorter stroke, which, of course, reduced the inertia effect. He thought the ratio was something like 38 to 30 when comparing a 30-inch stroke with a 24-inch. Moreover, with a 24-inch stroke and a 6-foot 2-inch wheel the piston-speed was reduced to about 1,090 feet at 60 miles per hour, in comparison with 1,160 feet with a 6 foot 9-inch wheel and a 28-inch stroke. As Professor Inglis had pointed out, springs with no frequency should be used. He had employed rubber springs, the rubber having no natural frequency, to damp out any ill effects and so prevent their transmission from the engine to the tender and from the tender to the train No ill-consequences on the engine had been observed owing to this departure from conventional practice. Mr. Ellson had shown some diagrams to illustrate the effect of a two-cylinder engine. The balancing weights had been altered to remove the reciprocating portion, but it was not possible to be quite certain, in view of the results, that the engineers had succeeded in doing what they set out to do, and they would be compelled to re-balance the engine and make a further test. Locomotive engineers looked forward to higher speeds and were particularly anxious to be allowed heavier axle loads. Only by multiple-cylinder engines, however, and with no reciprocating weight balanced, were they likely to induce the engineer to give them what they wanted.

Mr. W. K. Wallace said that higher speed was becoming general, and that made balancing more important than in the past. Moreover, the railways were developing mixed-traffic locomotives with smaller wheels, and those, due to improved valve gear, ran more quickly. Even though a train might not be timed to run at a high speed, if the engine-driver wished to make up time high speed might be produced in any case.

It was very important to obtain light weight motion for two-cylinder engines. He liked the London and North Eastern Railway reciprocating weights, because the permanent way engineer wanted a small hammer-blow which controlled the design of permanent way. He agreed that engineers were more interested at present in impact on the permanent way in the sense of the track than on bridges, because they were probably nearer the limit of stress in respect of rail and permanent way than in respect of bridge structures.

Mr. Johansen had mentioned that it was thought that the engines of Class 5 had an effect upon the road. There was no doubt about it, and that was one reason why they had conducted the tests which had been filmed.

Mr. Wallace was perfectly prepared to grant Mr. Stanier additional axle weight if he did away with hammer-blow. On the other hand, it was essential to ensure that no damage should be done by the older class of engines running at the higher speed. If the operating people were given a small class of new engines to speed up specific trains which they were re-timing, a number of other trains for which there was not a specific high-speed engine available would be speeded up also, and some more serious effects might ensue.

It was interesting to note in Mr. Cox's Paper the remark that nosing need not receive much attention in a locomotive, because he had been rather afraid that it might be said that if reciprocating balance were omitted trouble would arise from nosing. It was quite obvious that the locomotive engineer would not give trouble in that respect.

The chief thing from the permanent way engineer's point of view was to reduce the hammer-blow as much as possible. He would like to omit reciprocating counter-balance altogether if possible, but if the locomotive engineer found that that led to lateral motion which would also abuse the track (and the track was not so stiff against lateral loads in Great Britain as in countries where flat-bottomed rails were used) that counter-balance would have to be tolerated ; but the use of lighter motion and anything else that would tend to reduce hammer-blow was all to the good.

No doubt a demand for more ultra-high-speed trains would arise after the war, and he did not know that it would be possible to require that such trains, as hitherto, should have a limited seating capacity. Whereas the " Coronation Scot " was a limited train, after the war similar speeds might be required with a train about the weight of the " Royal Scot." Of course, those engines were not so serious from the permanent way point of view, because they were always multi-cylinder, as they required such a large tractive effort. But the two-cylinder mixed-traffic engine with a modern valve gear, which gave a high rotational speed, was the one which permanent-way engineers needed to watch.

There was one other observation he desired to make after watching the film, namely, that Mr. Cox ought to return thanks to the gangers and platelayers, for his engines did everything but roll !

Mr. Conrad Gribble referred to the pleasure experienced by members of both Institutions at the opportunity of discussing the two Papers together. He would reinforce some of the arguments of the Authors by referring to the particulars of locomotive hammer-blows given in Appendix D of the Bridge Stress Committee's Report. Those data set out the position as regards the balancing of reciprocating parts as it was at the end of the Committee's work about 14 years ago and showed that every possible variation of practice existed, occasioned either by reason of different methods of design or by errors of design or manufacture. For instance, in four-cylinder engines one class was noted which had no hammer-blow at all, owing to no portion of the reciprocating parts having been

balanced. In another class the hammer-blows at 5 revolutions per second were as high as 4·6 tons on a wheel.

In the former class where all four cylinders drove the same axle the effect of the reciprocating parts was ignored. In the latter class, where the inside and outside cylinder respectively drove separate axles, each system was treated as an individual two-cylinder engine. Coming to three-cylinder engines, certain classes had practically no hammer-blow on the whole engine and no more than 2 tons on a wheel at 5 revolutions per second. Other classes of three-cylinder engines had total hammer-blows as high as 6·9 tons, axle hammer-blows of nearly 6 tons, and wheel hammer-blows of 6·6 tons. In two-cylinder engines, however, the variation was most marked and most important. There were engines having total hammer-blows of 20½ tons, axle blows of 11½ tons, and wheel blows of 6½ tons. At the other extreme there were two-cylinder engines with less than 1 ton on the whole engine, less than 2 tons on an axle, and less than 1 ton on a wheel.

The favourable conditions, from the bridge engineer's point of view, in those last-mentioned classes were caused by the absence of any considerable balance weights for reciprocating parts. There were certain engines, however, where not only were there no balance weights for reciprocating parts but also a deficiency of balance weights for rotating parts aggravated the effect of the absence of the former. In view of that state of affairs it had always seemed to Mr. Gribble that it would be difficult for locomotive engineers to justify their practice of balancing 50 or 60 per cent., bearing in mind the numerous engines which were discovered to have been in service for many years having none, or less than none, of their reciprocating parts balanced without anyone being any the wiser or a penny the worse. At the end of the Bridge Stress Committee's work the locomotive engineers agreed to limit the hammer-blow on new engines to $0{\cdot}5r^2$ tons (where r denotes the number of revolutions per second) and on any axle to $0{\cdot}2r^2$ tons. Although that limitation was not to be despised it did not go very far. So long as the maximum speed of revolution did not exceed 6 revolutions per second the rule limited the whole engine blow to 18 tons and the axle blow to 7·2 tons.

If engineers were to be faced with speeds as high as 8 revolutions per second, such engines might inflict hammer-blows of 32 tons on the whole engine and 12·8 tons on an axle. The latter value would probably represent a wheel-blow as high as 9 tons, which was a serious force. Since the agreement was made most of the large engines turned out had had three or four cylinders, in which types there was a consensus of opinion that large hammer-blows were unnecessary; but comparatively little improvement had been made from the bridge engineer's point of view in the balancing of two-cylinder locomotives which, of course, comprised by far the largest proportion of engines in Great Britain. The worst offenders discovered 14 years ago were dealt with by the locomotive engineers, but as the

agreed limits already referred to were not specially stringent there had not been the wholesale reduction of hammer-blow which many engineers considered might well be brought about. It was extremely unlikely that any of those two-cylinder engines would be put into regular service on the high-speed trains for which engine-frequencies of 8 revolutions per second were suggested, but it was clearly of the utmost importance that even in emergency that should not be permitted and that such trains should invariably be drawn by locomotives specially built for the purpose. The Bridge Stress Committee were of opinion, in 1928, that speeds of 6 revolutions per second would be the maximum for which provision should be made, and that although a speed of 6·5 revolutions per second might on occasion be attained, that was to be considered as exceptional, and they certainly never contemplated speeds of 8 revolutions per second. During their tests with engines running light, speeds exceeding 7 revolutions per second were attained on a number of occasions by goods locomotives having wheels about 4 feet 6 inches in diameter. Actually a speed of 7·36 revolutions per second was recorded on one run. The celebrated locomotive "K" at 7 revolutions per second produced a hammer-blow of about 30 tons and was extremely useful as a test-machine. No one contemplated such speeds and such hammer-blows becoming general.

The experimental work carried out by Mr. Bulleid in connexion with the "Merchant Navy" class of three-cylinder engines which had no hammer-blow was a step forward, as in recent years several classes of three-cylinder engines had been built in such a manner as to produce quite an appreciable hammer-blow on a wheel, if not on the whole engine, and that demonstration that such hammer-blows could be eliminated was very welcome. Still more important, perhaps, was his further series of experiments in eliminating hammer-blow in two-cylinder engines on the lines of those described by the joint Authors as having taken place in India. Such work would be warmly welcomed by all bridge and permanent way engineers.

Lieut.-Col. Sir Alan Mount observed that he had had the honour of leading the Pacific Locomotive Committee to India in the autumn of 1938. The Authors of the first Paper appeared to be righteously indignant at some remarks of the committee concerning two of the engines on the Madras and Southern Mahratta Railway. He sympathized with them on reading again what was said on that occasion, but he would remind them, as Mr. Stanier had done, that during the tour of 7,000 miles the Committee had covered nearly half that distance on the footplate of twenty-nine engines—incidentally, in very hot weather—and they were not inexperienced.

Moreover, their opinions with regard to track conditions were fortified by the Hallade recorder, and they were as much impressed with the Madras and Southern Mahratta track as with that of any other railway in India, perhaps more so, particularly the length referred to between Arkonam

and Madras, which had been described as "a particularly good road, on which speed up to 65 m.p.h. would appear to be justified." He had just received the conclusions of the Government of India on the accident which took place at Bihta in July 1937. That accident was attributed, as was to be expected, to a combination of three factors, namely, engine, track, and speed. As a border-line case, the engine was exceptionally sensitive to track irregularities, but no case of "hunting" had been established which could be attributed merely to the engine and its speed. The Authors would therefore be interested to learn that the Madras and Southern Mahratta Railway had been picked out as an example showing that not a single case of track distortion had occurred, although their "Pacifics" had been constantly running on the Madras–Arkonam section at speeds exceeding 60 miles per hour.

He agreed that it was exceedingly difficult to isolate the effect of one feature of an engine, but he made no excuse for what had been said in the observations cited. Those observations were really a running commentary of the Committee's impressions, recorded as faithfully as possible every night as the result of discussion and of information received. Of course, riding on the footplate did not furnish a scientific analysis of engine vibration, but it did indicate any marked difference from normal behaviour, and he noticed that many of the Authors' statements in the first Paper were based upon footplate experience by drivers or inspectors. He was sure that the Committee would have been criticized if they had not recorded their own practical experience, but that was not the sole basis of their conclusions, and they had made it clear that such observations were merely, to quote the Report, "intended to be of a general nature and naturally related to conditions as they appeared to exist at the time." Mr. Stanier had said that they did feel, on the occasions in question, on both the Madras and Southern Mahratta engines (a "Pacific" and a 4–6–0), a fore-and-aft movement at about 10–15 miles per hour, which tended to die away as the speed increased. That must have been due to the effect of the unbalanced reciprocating parts. Mr. Cox now suggested an explanation for that movement, and the fact that it was less on the heavy "Pacific" than on the lighter B.E.S.A. 4–6–0 type seemed to confirm what he had said in his Paper. Sir Alan would not try to enter into any technical discussion, but he was particularly glad that Mr. Cox had made his valuable contribution. It was no secret that, under Mr. Stanier's guidance, he had been responsible for much of the Committee's report.

With regard to one aspect of hammer-blow, a few years ago there had been in Great Britain high-speed derailments of both tank and tender engines which were difficult to account for satisfactorily, although in two cases relief of weight owing to the upward or negative phase of the hammer-blow might have been a contributory factor. When normal times returned the whole subject of the riding of engines on the track would require more

investigation, and when the testing-station had got going, with flange stress recording instruments, a great deal of experimental work would be waiting to be done, not only to establish the effects of the unbalanced parts in a locomotive under high-speed operation but also to define the limiting value of permissible disturbances.

Mr. E. C. Poultney said that he felt himself to be in a difficult position for if he had listened only to the Paper presented by Sir Harold Colam and Major Watson, he would have left the meeting convinced that the balancing of the reciprocating masses was not required.

Conversely if he had heard only the Paper by Mr. Cox he would have made up his mind that some balance of the reciprocating parts was necessary; but having heard both Papers, he hardly knew what to think. He was glad that Mr. Stanier had mentioned the Hallade diagrams put forward by Major Watson; he also could not understand them, and they did not, he thought, convey anything.

With regard to the general question of balancing he agreed entirely with Mr. Cox that modern conditions had brought the matter very much to the fore. The larger engines now used and the high maximum speeds attained had forced attention to the hammer-blow effects produced by the overbalance added to take care of the reciprocating masses. One point he wished to make was that that had been accentuated by the change-over that had taken place from the use of "inside"-cylinder to "outside"-cylinder locomotives. He considered that important because the adoption of outside cylinders for two-cylinder engines had by itself increased the amount of counterbalance required for given reciprocating masses by at least 50 per cent. He exhibited two slides illustrating that point. One showed at a glance the difference in the magnitude of the balance weights for "inside" and "outside" cylinder engines with equal reciprocating parts, and the other showed the relative hammer-blow effects at various speeds, indicating the increase in the case of the outside-cylinder engine which, for the particular example given, was 55 per cent.

In round figures, it could be stated that 75 per cent. of the weight of the reciprocating masses per cylinder for an "inside" cylinder engine was sufficient to balance fully those parts, whilst if the cylinders were outside the balancing weights had to be 20 per cent. greater than the parts to be balanced.

Mr. J. J. C. Paterson said that the question of balancing had been a vexed one for many years and the information afforded in the Papers would be very useful. He thought, however, that it was advisable to draw attention to the possibility of confused thinking on the matter unless the value which speed had in all those arguments was realized. What could be done at a speed of 60 miles per hour was very different from what was permissible at round about 120 miles per hour.

The first Paper was essentially based upon experience with moderate speeds of 60–65 m.p.h., whilst Mr. Cox's Paper obviously dealt mainly

with high-speed operation, although at times lower speeds were mentioned. Experience in India confirmed the fact that two-cylinder engines could probably be run without reciprocating balance, but that again was confirmed only up to a speed of 60 miles per hour. As a matter of fact, some later information on the subject was available. Two " Pacific " type locomotives were tested and recorded for flange forces and for the amplitude of swaying movements. One locomotive had 66 per cent. reciprocating parts balanced, whilst the other had nil balance. The results indicated that both locomotives were perfectly satisfactory so far as the values of the flange forces were concerned and the amplitude of the sway was exceedingly small; in fact, there was nothing to choose between the locomotives at 60 m.p.h. Incidentally, both locomotives had a definitely sinuous characteristic, but the amplitude was so small that he supposed there was no harm in it.

Another point which he desired to make was with regard to the amplitude of the oscillation. It was not perhaps realized how small was the permissible movement in the transverse plane. If there was an angular displacement of, say, $1\frac{1}{2}$ degree on either side of the mid-position, the result was an oscillation of an amplitude which was very large for a locomotive. In fact, if the oscillation were continuous and resulted in a "hunt," an observer riding on the footplate would probably find it alarming.

The question was whether a condition of affairs in which the forces acting upon the mass and tending to produce movement should be allowed. The tendency in all branches of engineering of a similar character was to produce a perfectly-balanced engine or prime mover so that the forces acting on the mass would be zero. In locomotive engineering the process was in a totally different direction so far as the two-cylinder engine was concerned. He mentioned that because, although there might be good reasons for proceeding in a contrary direction, it appeared at first sight to be a retrograde step.

He would not enter into technical detail, but it was of interest to take stock of the position, and almost sufficient information was available. What was the actual position with regard to the problem of balancing? He raised the point because to some it was just a technical matter, whilst to others it was a matter of considerable financial importance. At the back of this problem of balancing a big money question loomed on many railways.

Consider a high-speed railway, and assume that the bridge engineer were given all that he wanted, hammer-blow being abolished or reduced to a negligible amount. What, then, was the position? The position, so far as he could see from Mr. Cox's Paper, was that a multi-cylinder engine must be built. If a two-cylinder engine were built and a compromise made on the balancing, the bridge engineer would not be satisfied. At least that was true of the bridge engineers with whom Mr. Paterson had

had discussions, but perhaps Major Watson could give further information on that point. That would not cause much difference to English practice because the later examples of high-speed engines in England had throughout been of the multi-cylinder type. But it raised the point as to what would happen to all the existing two-cylinder engines that must continue running for a considerable number of years before it would be possible to work the entire section with completely balanced multi-cylinder engines.

On a railway which was typical of Colonial railways, and of a good many foreign ones on which speeds were limited to 60 miles per hour, a very different condition of affairs prevailed. A multi-cylinder engine could be built, but equally, on the other hand, a compromise could be made with the reciprocating balance of the two-cylinder engine whilst in all probability still furnishing the bridge engineer with all that he wanted. He thought that for the moderate-speed railway that was a very fortunate circumstance. It also undoubtedly opened up a considerable possibility in railway policy.

Mr. Stanier had raised the question of who was going to have the benefit. The benefit of reducing the hammer-blow could be realized in two directions. It could be given to the bridge engineer to save steelwork, maintenance, and so forth, or it could be given to the locomotive engineer, who might be allowed to increase his axle load and reduce his cost of haulage. Every case would have to be considered on its merits; but if the case as it existed on a considerable number of foreign railways where the track had been relaid to a higher standard, were taken, and a large number of trains were operated over the complete length of line, a good argument could be made out to show that over a number of years it would pay to increase the static axle load in preference to trying to save money by endeavouring to retain a somewhat weaker bridge.

⁂ **Mr. V. A. M. Robertson** observed that moving parts in locomotive mechanism might be considered as reciprocating or revolving. The revolving parts might be balanced fairly easily on their own axle and, as that could be done in most cases, little difficulty arose. The reciprocating parts, however, presented a more complex problem, owing to the changing direction and magnitude of the force which they exerted on the locomotive frame. The balancing was tackled in a compromise fashion by adding eccentric weights on the driving-wheels instead of installing a complicated system of bob-weights or counter-reciprocating motions. Those "balancing weights," although benefiting the performance of the locomotive mechanism, unbalanced the wheels and caused variation in the wheel–rail reaction when the wheels revolved. Naturally, the hammer-blow had a harmful effect upon the track and track structures at high speeds, especially when slipping of the wheels also occurred. The greater the proportion of reciprocating parts balanced, the greater were the

⁂ This contribution was submitted in writing.

eccentric masses required on the wheels, and the resulting hammer-blows on the rail. A second harmful result of unduly increasing the amount of balancing undertaken occurred at the higher speeds when the hammer action, which at a maximum was twice per wheel-revolution, acted in an upward direction, causing the wheel to lift from the rail. The resulting hammer-blow when the wheel returned to the rail might thus be very great in certain circumstances, stressing the rail beyond its elastic limit and causing "kinking." Therefore, the counterbalancing of reciprocating parts was necessarily a compromise between the permissible unbalance in the plane of reciprocation and the allowable dynamic loading at the rail.

The horizontal components of the forces due to unbalanced reciprocating parts could be resolved into :—

(*a*) a horizontal alternating coupling on the locomotive frame, which caused a nosing action ;

(*b*) a varying longitudinal force on the locomotive frame which, in the drawbar, was superimposed on the tractive effort due to steam-pressure in the cylinders, also varying, to give the total tractive effort available.

In early two-cylinder locomotives, wherein the ratio of locomotive weight to weight of reciprocating parts was not so high as in modern locomotives, the unbalanced reciprocating mechanism had relatively greater effect upon the running. To-day, the reciprocating masses were being reduced in weight by the use of special steels, and the total weight of the locomotive was tending to increase. The locomotive's greater inertia had a larger damping effect upon the nosing couple, but that was offset to some extent by the higher speeds now obtaining, which had increased the magnitude of the disturbing forces.

Mr. Robertson considered that much investigation was still required to reduce the problem to its elements and establish facts upon which decisions for future practice might be based. For instance, locomotives were apparently in existence which rode and wore well with no reciprocating parts balanced, whilst other locomotives required counterbalancing to widely varying degrees. The amount of counterbalance might vary from zero to 85 per cent.

He would like to put the following questions to Mr. Cox :—

1. Was it possible to reduce nosing by increasing the effective length of the locomotive by designing a special coupling between the engine and tender which had a damping effect on relative lateral movements ?

2. How did the articulated locomotive compare with that of normal design as regards lateral oscillation ?

3. If three-cylinder and four-cylinder engines cut down the necessity for balancing reciprocating parts, could that be a sufficient reason for omitting two-cylinder types from future construction for high-speed operation ?

4. What were the prospects of the turbine locomotive, which had little hammer action problem, superseding the piston type for heavy high-speed operation ?

5. Would it be practicable to introduce a certain amount of springing into the cab-floor to absorb in part the more violent oscillations of the engine frame ?

Mr. Cox had stated (p. 246) that "the final criterion as to the percentage of balancing necessary is the magnitude of the oscillations which can be admitted on the engine, having regard to riding comfort for the engine crew and passengers, wear and tear, maintenance costs, and safety." His Paper gave the impression that although information was scarce on the subject, the wear and tear on under-balanced locomotives was not only not great but also had not increased to such an extent that the rougher riding, which would be expected to develop, was noticeable. The Authors of the other Paper seemed to hold similar views.

It was very desirable that the engine designer should be aware of the nature of track problems: for instance, he might not realize that the nature of the track construction brought a hammer-action problem from all rolling loads, which, although not so evident, and of smaller magnitude, was probably a leading factor in rail wear.

The permanent way engineer's difficulty included the number of varying factors to be considered in reducing the problem to an approximate mathematical picture of what actually happened. Much ingenious theory had been developed to explain the actions which took place, but, although helpful in some degree, it was still mainly speculative and could not be said to have led directly to any major improvement. In 1918 the American Society of Civil Engineers formed a committee to investigate stresses in railroad tracks and, about 10 years later, a report was published in which it was indicated that hammer-blows from locomotives did not normally increase the maximum rail stresses unduly. Mr. Robertson did not know whether that Committee was still in existence, but he felt that the whole problem (particularly with higher speeds) was so pertinent that a British Committee, possibly operating under conditions similar to those of the Bridge Stress Committee (1923–28), or even an International Committee, should be formed as soon as world affairs allowed, to investigate all aspects of the inter-relationship of moving loads on railway track. Civil and mechanical engineers, naturally, should take the leading part and members chosen should be those who were directly concerned from day to day with rolling-stock structures and track and bridge problems.

In reply **Major Watson** observed that the Hallade records had been criticized, and quite rightly so. They were extremely bad; but it so happened that the instrument had been fitted on the locomotive and those results obtained, and in preparing the Paper the Authors had thought that it would not be right that those records should be suppressed, and therefore they went in. He did not think that they meant a great deal :

the only thing that could be said was that they could be compared with one another. There was far more difference between the records of an engine which had just come out of the shops and of one which was near an overhaul than there was between the records of two engines which had run just about the same time since their overhaul and were normally balanced or without reciprocal balance.

Part of his duty had been to " vet " engines on the Madras and Southern Mahratta Railway and to say on which sections of line they could run. It had to be made a rule that when an engine was rebalanced it became of a different class and came up for examination again, and on several occasions he had been able to permit a locomotive after rebalancing to run on certain sections where it had not been allowed to go before. He thought that engineers would agree with him that that was a distinct benefit to the line.

Mr. E. S. Cox, in reply, stated that he was interested in the Chairman's suggestion for a non-resonant drawbar spring, which should take care of cases of low-speed resonance such as had sometimes proved troublesome. He could not quite agree that longitudinal oscillations were quantitatively quite insignificant on all engines, as witness the upper part of *Fig. 13* (p. 242, *ante*). He had suggested the point at which they ceased to be insignificant, and whatever value was chosen for that, it presupposed that certain engines would still have to have some reciprocating balance and consequently some hammer-blow. That was illustrated further by Mr. Stanier's reference to the 2–6–4 two-cylinder tank engine which had run for some years without any reciprocating balance. Such an engine, weighing 90 tons with only 677 lb. reciprocating parts per cylinder, did not produce longitudinal oscillations at any speed greater than were suggested as permissible in *Fig. 10* (p. 238, *ante*). The Class 5 two-cylinder engine weighing 72 tons with 933 lb. reciprocating parts per cylinder, on the other hand, was liable, if the parts were not balanced, to produce a shaking at the drawbar which would be quite inadmissible.

The remarks of Mr. Ellson and Mr. Bulleid were very valuable, as giving first-hand practical confirmation of the contention that reciprocating balance could be totally eliminated in three-cylinder engines, and from the evidence produced the riding of the " Merchant Navy " engine seemed to leave nothing to be desired. It was clear that the short stroke on that engine reduced the inertia forces for each individual cylinder, but since the longitudinal effects of three cylinders cancelled out, and the nosing effect was of negligible magnitude in any case, he did not see that anything tangible had been gained by using that short stroke. Mr. Ellson, whilst making a plea for the abolition or major reduction in hammer-blow on the heavier classes and those running at speeds above 6 revolutions per second, stated that there was no need to alter locomotives running at ordinary fast speeds. The crux of the matter, however, as had been pointed out by Mr. Wallace, was that if schedules were altered to introduce some fast trains, others might be affected, and any modern engine

was capable of 8 revolutions per second, whether mineral, tank, mixed-traffic, or express.

Each class, therefore, required equal attention and in so far as some degree of reciprocating balance might still be required in certain of the two-cylinder engines, reduction in the weights of the reciprocating parts themselves was still of major importance. Mr. Wallace had also referred to nosing and to the way in which it had been dealt with in the Paper. It was necessary to be very clear that it was only that element of nosing which arose from unbalanced reciprocating parts which appeared to be negligible under present conditions. That part which arose by virtue of the engine as a vehicle on the track was by no means negligible; and by that Mr. Cox referred to the factors of lateral track stiffness and locomotive side control—matters outside the scope of the Paper.

Mr. Johansen had drawn attention, in connexion with the film, to the form of the nosing movement at the back end of the mixed-traffic engine. Mr. Cox thought that a little care was necessary in considering that movement, because it was made under rather artificial conditions, in which the front end of the engine, as Mr. Johansen had rightly pointed out, was being held by the friction of the bogie, and only the back end of the engine was really free to move. If it had been possible to sling the engine up in chains, as was done in some of the early balancing experiments, or even under the conditions of the engine running at speed on the track, it was much more likely that its behaviour would have been of the nature of oscillating about the vertical centre of gravity, as theory suggested that it should do.

He wished to emphasize that, fortunately, the phenomena shown in the film did not always occur when such an engine was running along the track at 100 miles per hour or even every time it slipped at that speed, but occurred only at rare intervals when the interdependent track and engine conditions were favourable.

Mr. Cox agreed with Mr. Train that the subject of flange forces and vertical wheel loads required close investigation. In India flange forces of the same order, namely, up to 6 tons on straight and 13 tons on curved track, had been experienced. Tests made in France had indicated that derailment due to the flange climbing the rail was likely to occur after the vertical load was reduced to half the flange force. Even, therefore, where flange forces were most reasonable—3 or 4 tons—derailment was a potentiality should the leading coupled wheel become practically unloaded owing to the centrifugal action of the balance weights. Even although all the contributing factors might only very rarely coincide to produce an actual derailment, it was a powerful argument in favour of reducing reciprocating balance, and, as Sir Alan Mount had suggested, could not be left out of account in investigating certain derailments. It was hoped after the war to be able to record flange forces and vertical axle loads continuously and simultaneously.

Mr. Gribble had referred to the four-cylinder "Claughton" class on the old London and North Western Railway—a type now defunct—and although it had certain defects, certainly bad riding due to lack of balance was not one of them. There appeared to be no reason why all four-cylinder engines having adjacent cranks at 180 degrees should not run quite satisfactorily with nil reciprocating balance.

Mr. Cox thought that Mr. Poultney would agree that there were very few inside-cylinder engines in existence so designed as to be capable of sustained speeds of 8 revolutions per second. The disadvantages of that type of engine were too many to provide any temptation to return to itfor the sake of being able to balance a higher percentage of reciprocating parts with the same hammer-blow as on a corresponding outside-cylinder engine.

Mr. Cox could not quite agree with Mr. Paterson on the subject of speed. Hammer-blow effects, and nosing and hunting due to the action of the engine as a vehicle on the track, certainly increased with speed, but there was no evidence that the effects of unbalanced reciprocating parts on the engine, considered by themselves, were any greater at 120 miles per hour than at 60 miles per hour.

Mr. Paterson had posed the question whether total hammer-blow elimination did not require all engines to be multi-cylinder, and had shown how serious a financial matter that might be to Colonial railways. Actually however, *Fig. 10* by no means showed reciprocating balance to be necessary for all two-cylinder engines. When they had a ratio of reciprocating weight per cylinder to total engine-weight of less than about 1/300 such balancing did not appear to be required at all; and it was probable that many of the heavier Colonial engines satisfied that requirement.

In reply to the specific questions raised by Mr. Robertson :—

(1) The proposal made had been attempted with the French "Meistre" coupling between engine and tender which had also been tried out in India. Whilst it controlled nosing to some extent on straight track, on curves it tended to cancel the effect of the leading bogie control and actually cause nosing and increased coupled-wheel flange forces. It could not be considered satisfactory, therefore, although it would tend to damp out any longitudinal oscillations arising from unbalanced reciprocating parts.

(2) So long as the individual units were suitably designed as regards side control, articulated locomotives of the Garratt type were very free from lateral oscillations. The large weight of the engine as a whole effectively damped out longitudinal oscillations.

(3) The answer was "no", because, as had been already shown in the reply to Mr. Paterson, two-cylinder types could be built with nil hammer-blow if sufficiently heavy in relation to the weight of the reciprocating parts.

(4) A multi-cylinder engine produced no fore-and-aft movement and negligible nosing action arising from its reciprocating parts. The claim of the turbine engine to supersede the normal type would therefore have to be based on other grounds.

(5) It was better to remove the cause of undue vibrations than to seek to introduce a palliative.

Mr. Cox agreed that in all locomotive riding problems track conditions had to be considered at the same time. Both elements were part of the same machine.

The full reply of Sir Harold Colam and Major Watson to the Discussion will be printed in a subsequent number of the Journal.—Sec. Inst. C.E.

INGENUITY COMPETITION, 1941.

"Freetown Waterworks Construction, Sierra Leone, West Africa."

By Sydney Hamilton Lloyd, Assoc. M. Inst. C.E.

Between the years 1912 and 1916 the Author was Resident Engineer for the late Mr. H. Howard Humphreys, M. Inst. C.E., on a scheme which consisted briefly of the construction of head dams in the Babadori river and two of its branches and the laying of a gravity pipe-line through the bush around the lower slopes of Sugar Loaf mountain to convey the water to the reservoir in Freetown. Pumping machinery was also installed at a lower level in the river and the water which collected below the head dams was pumped into the main gravity pipe-line.

Thirty years ago Sierra Leone was a comparatively backward country as regards roads. Owing to the presence of the Tsetse fly there were no horses in the Colony, and as mechanical transport had not developed to any considerable extent, no incentive had existed to make roads, whilst such roads or tracks as existed, although adequate for the usual form of transport, namely, the carriage of loads of 60 lb. on the heads of natives, were not suitable for the passage of heavy machinery.

The problem of transporting the pumping machinery from the wharf at Freetown to the pumping-station was considered by the Author from all angles and the following method was decided upon. The cases containing the various units for the installation, which consisted of two 50-horsepower oil engines and two triple-ram pumps, together with an air-compressor and numerous parts—about fifty cases in all—were to be loaded at the wharf on to the mountain railway and sent by rail to the terminus at Hill station, where they were to be transferred to a truck running on iron wheels 6 inches in width, the front wheels being mounted on a bogey with a handle for steering.

From Hill station the Wilberforce–Regent road could be used as far as a point where a rough track descended the mountain-side, the total distance being about 1¾ mile. The route, contours, etc., are shown in *Fig. 1*.

The track for a distance of ½ mile from the top of the hill has an average gradient of 1 in 6, but in places is as steep as 1 in 3. It is only 6 feet in width, and on the west side there is practically a vertical drop into the bush.

The two pumps were the heaviest items, each being contained in a case 11 feet in length, 6 feet in width, and 4 feet 6 inches in height, and weighing 6 tons. It was decided to commence with one of the pumps, which was

unloaded from the railway on to the truck and conveyed to the point where the track starts, without any serious difficulty.

Before the descent was commenced, two stout ropes were attached to the back of the truck and passed around trees at the side of the track. A gang of about a dozen natives was assigned to each rope with instructions to pay out the ropes slowly. Another gang was placed in front to pull and steer the truck. When the truck had travelled a short distance, however, the front wheels sank into the soft surface of the track and it was found impossible to steer it; it was jacked up, the ruts were filled in, and a fresh start was made, with the same result; and the Author regretfully came to the conclusion that some other method would have to be devised.

It was considered that the pumps might be dismantled and taken down in smaller loads, but this was dismissed as it was impossible to obtain in the Colony fitters who could be trusted to take the pumps to pieces and reassemble them. Owing to the fact that only 5 months were available before the rains would commence, some scheme had to be decided upon at once. The annual rainfall in Sierra Leone is in the neighbourhood of 160 to 180 inches, all of which falls within 4 to 5 months (June to October) and the pumping machinery had to be not only transported by that time but also erected.

The Author, therefore, decided upon the following procedure: the main laying had been completed, leaving a number of short lengths of 9-inch steel pipes which, it was considered, could be used as rollers. The cases were accordingly jacked up and timber runners were fixed underneath longitudinally. (*Fig. 2* shows this operation, with a case still on the truck.) About twelve of the steel pipes were laid on the track, and a block and tackle, fixed to the front of the case and to trees in the bush at the sides of the track, was used to start the case travelling and also to keep it on the track (*Fig. 3*). Two ropes were fixed around the case and a double turn was taken around trees at the rear. The natives in front commenced to pull, while those at the back paid out the ropes slowly, and another gang picked up the pipes after the case had travelled over them and laid them in front ready for another length. *Fig. 4* shows a very steep part of the descent, with a left-hand bend in the track facing the camera; in this case the rollers were not used for a short time, owing to the gradient, but the case was moved down on timber runners. *Fig. 5* shows the case nearing the pumping-station on a fairly level section.

The Author supervised the operations at the front of the case and a European foreman at the back. After a few days the natives had grasped the idea, and everything worked smoothly. Two weeks were required to get the first case to the pumping-station, but the second case took only ten days. After about two months it was found that the native headman was capable of taking charge of the transport of the remaining cases and the foreman could be released to start the erection of the machinery.

In the Author's experience of about 35 years, this problem was the most difficult that he has ever had to tackle, since the slightest mishap

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 1.

Plan of Pumping-station Site.

might have caused the cases to overturn or fall over the precipice. If such a mishap had occurred, replacements could not have been obtained from England owing to the fact that these works were being carried out in war-time, and extreme care, therefore, had to be exercised to ensure that in no circumstances could any accident happen.

All the cases were transported successfully without the slightest damage or loss, and the installation was completed and in working order before the rains commenced.

The Paper is accompanied by a plan and four photographs, from which the Figure in the text and the half-tone plate have been prepared.

INGENUITY COMPETITION, 1941.

"The Rewinding of a Stator at Rangoon, Burma."

By Henry Nimmo, M. Inst. C.E.

Some years ago, when the Author was an assistant engineer working on the plans and layout of an extension to the Rangoon generating-station, he was faced with the problem of rewinding a 1,500 kilowatt turbo-alternator stator which had burnt out. Measured by to-day's standards the machine was small, but the difficulties of the emergency repair described could not be measured in terms of rated output. No experienced winders were available in Burma, and as the spare coils in stock represented only one-sixth of the total number required, a large number of new coils had to be made from the remains of the burnt coils. Moreover, no drawings were available, insulating materials were not readily to hand, and some tools had to be made.

In 1914 the Ahlone generating-station of the Rangoon Electric Tramway and Supply Company was equipped with four British Thomson-Houston vertical turbo-alternators generating at 2,500 volts, 3 phase, 50 cycles. No. 1 was rated at 700 kilowatts, No. 2 at 700 kilowatts, No. 3 at 1,500 kilowatts, and No. 4 at 2,500 kilowatts. The equipment also included a 500-kilowatt and a 300-kilowatt Belliss-Morcom traction set, making a total rated capacity of 6,200 kilowatts. The maximum demand was about 2,500 kilowatts.

On the evening of the 6th February the lights suddenly became dim, brightened a little, and then died out.

It was found that the failure had occurred at the generating station, and that No. 3 alternator had burnt out. The primary cause could not be stated with any certainty, but the trouble was thought to have started at a badly-sweated socket on one of the outgoing leads. The machine was carrying about 25 per cent. overload at the time, and the solder from this socket had melted and run out. An arc had started and, after continuing for a little time, flashed across to the next phase, causing a complete burn-out of two phases and considerable damage to the third. The rotor was practically undamaged.

The following morning, after examining the damage, the chief engineer instructed the Author to carry out the repair—although he did not say how it was to be done or where the materials were to come from!

The stator was a blackened mass, with molten copper run into the core at two or three places, and a large number of the end coils, as well as

nearly all the connector-bars, had disappeared. About 10 weeks would be required to procure new coils from the manufacturer, whereas it was imperative to get the machine running again as soon as possible because the supply to the city was mainly dependent upon No. 4 machine, any failure of which would be very serious with No. 3 still out of commission. Fortunately during the succeeding weeks No. 4 ran perfectly.

At that time there was no one available with any experience in winding a stator. Some years before, as an erection engineer with the British Westinghouse Company, the Author had helped to rewind a burnt-out alternator at Coatbridge, but then he was only assisting two experienced winders provided with drawings, tools, and a complete set of new windings. That experience was now to prove very useful.

At Rangoon he had only the station fitters and wiremen (Burmese and Indian), none of whom had ever seen a generator-coil fitted. The Company's English cable-jointers were also called upon, although many of the joints were actually made by an Anglo-Indian, whose work was extremely good.

The total number of coils required was 216 ; half of these had to be made from the remains of the burnt coils, and the other half was made up of the thirty-six spare coils and the seventy-two coils of the third phase—which required new insulation.

Some of the burnt coils were not seriously damaged, but in a number of cases two—or even three—burnt coils had to be used to make one new coil. It was felt that if joints could be avoided in the slots, it did not matter how many joints occurred outside, so long as they were well made ; and with first-rate cable-jointers on the job no fear was felt on that score.

Insulating materials presented a problem, but an electrical shop in Rangoon was able to supply some sheets of yellow Empire cloth, which were cut into strips and rolled. The thickness of insulation was, of course, governed by the internal dimensions of the slots, and as the potential difference between turns was relatively low, and special precautions could be taken between phases, the Empire tape was regarded as suitable. White cotton tape was used to protect the Empire tape outside the slots.

As no drawings were available, a sketch of the connexions was made before the burnt coils were dismantled. The Burmese and Indian assistants then pulled out the old coils and chipped out the molten copper from the core. The slots were very carefully smoothed, pressed paper and Empire cloth insulation was put into place, and the newly-made coils were fitted into position.

Meanwhile connectors were being made and insulated, clips tinned and shaped, teak packing-pieces made, and teak wedges prepared for the top of the slots to hold the windings in place.

Work went on from 7 a.m. to 6 p.m. each day and nobody was allowed to touch the stator in the Author's absence. At night each end of the

stator was closed by a wooden frame carrying a board with a ring of carbon filament lamps projecting inside the core to keep the windings warm and dry. The machine was roped off and the greatest precautions were taken to protect the work.

Insulation tests were made as the fitting of repaired coils proceeded, and also every morning, and the results were uniformly good. The work proceeded according to plan and all joints were kept outside the slots—although a few were very close to the core.

When all the coils were in place and all the joints made and insulated, a current of twice full load was applied and every joint was carefully examined for excessive temperature-rise. Several of the joints were remade—some of them two or three times—until it was not possible to observe any difference in temperature around the whole stator. The senior cable-jointer was very helpful, and without him the difficulties would have been much greater.

Owing to the heat from the carbon lamps at night and from the intermittent overload current on several consecutive days, the insulation was very dry, even in the highly humid atmosphere of Burma. After further continuous drying-out and the application of shellac varnish coatings, a pressure test of three times normal voltage was applied successfully for one hour, and was repeated before the stator was lifted into position. The rewound stator had successfully withstood the current and voltage tests—neither of which was governed by any British Standard Specification—and confidence was felt that it would not burn out again.

By the end of March the machine was run up to speed, and fortunately the phasing was found to be right. The shift engineer synchronized without difficulty, and No. 3 alternator was again running in parallel with the other machines.

After the set had been run at various loads up to 25 per cent. overload and a number of turbine tests had been made, it was handed over to the station superintendent with the assurance that it would not burn out again.

New coils had been ordered from England in case of failure of the emergency repairs, but the machine was back in regular service several weeks before the new coils arrived, and they were never used.

When the Author returned to Rangoon nearly six years later he learned from the shift engineers that No. 3 had given excellent service and was regarded by them as the most reliable machine in the station.

MADE AND PRINTED IN GREAT BRITAIN BY WILLIAM CLOWES AND SONS, LIMITED, LONDON AND BECCLES.

NOTE.—*Pages* [1] *to* [8] *can be omitted when the Journal is bound in volume form.*

NOTICES

No. 4, 1941—42

FEBRUARY, 1942

MEETINGS, SESSION 1941—42.

ORDINARY MEETING.

The following Paper will be discussed on the date shown :—

1942.

Mar. 10 (Tues.) (2 p.m.). * † "**The Surface Finishing of Concrete Structures,**" by Norman Davey, B.Sc., Ph.D., M. Inst. C.E.

SIR CHARLES PARSONS MEMORIAL LECTURE.

The Parsons Memorial Lecture, entitled "Sir Charles Parsons and the Royal Navy", will be delivered by Sir Stanley V. Goodall, K.C.B., O.B.E., R.C.N.C., Director of Naval Construction, at 3 p.m., on Thursday, 26 March, at the Royal Society of Arts, John Adam Street, Adelphi, London, W.C.2. Advance copies of the Lecture will not be available, and admission will be without ticket.

SPECIAL ANNOUNCEMENTS.

MINISTRY OF LABOUR.

SCHEDULE OF RESERVED OCCUPATIONS.

Details of the following appear at pp. [2]–[3] of the January Journal:—

(*a*) Schedule of Reserved Occupations (Revision, December 1941) as affecting Civil Engineers.

(*b*) Progressive raising of ages of reservation.

(*c*) Deferment of calling up of men not reserved.

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* A brief Synopsis of the Paper appears at p. [7], *post.*

† Advance proofs, for those who intend to be present, will be available about a fortnight before the meeting, and copies may be obtained upon application to the Secretary.

MILITARY SERVICE.

Announcements in regard to the posting of Students of The Institution to the Royal Engineers and to registration in the Army Officers' Emergency Reserve appear at pp. [4]–[5] of the January Journal.

ROYAL AIR FORCE VOLUNTEER RESERVE.

Applications are invited for commissions in the Works Services of the R.A.F.V.R. The following is an extract from the Order defining the requirements in regard to Works Officers, and members of The Institution who desire to apply may send their names to the Secretary (with *brief* details of their engineering training and experience), with a view to transmission of such application to the Air Ministry :—

> "Candidates must possess a civil engineering degree or have passed the final examination for Associate Membership of The Institution of Civil Engineers, or produce evidence that they hold equivalent qualifications. They must also have had considerable experience on general engineering works (preferably including building construction, reinforced and plain concrete work, waterworks reticulation systems, sewage, steelwork, road construction, military works and land preparation and drainage). Experience in the organization of Works Services in the field and in the control of labour is also very desirable.
>
> "Selection will normally be confined to candidates between the ages of 26 and 35, but candidates outside these age limits may be considered if they have exceptional qualifications and experience."

GENERAL ANNOUNCEMENTS.

ELECTION OF COUNCIL.

The Council give notice that in selecting the names of Corporate Members to appear on the Balloting-List for the election of the Council for the year 1942–43, in accordance with the provisions of the By-Laws, they will be pleased to consider any names which may be suggested by individual Corporate Members, provided that the names are communicated to the Secretary on or before Saturday, 14 March.

The consent of each person proposed must first be obtained by the Corporate Members submitting names, and they must also state the occupation of the person proposed, namely, whether in practice, or holding an official position, or in other employment.

THE JOURNAL.

The next Number of the Journal will be published on the 16th March.

INVITATION TO PRESENT SHORT PAPERS.

The Council are prepared to receive short Communications of, say, 2,000 words, accompanied by two or three illustrations, for inclusion in the Journal. Such Communications should be topical in character and might deal, for example, with demolition and reconstruction problems, or with minor constructional details, of a novel character, which would be of general interest to engineers.

TRANSLATIONS.

Inquiry is received occasionally for assistance in regard to translation from foreign technical literature or documents, and the Secretary therefore invites Members and Students who are able to undertake such work to forward for record a brief note of the subjects with which they are prepared to deal and of the language(s) from which they are able to translate technical matter.

NEW YEAR HONOURS.

The Council have much pleasure in congratulating the following members on the Distinctions conferred upon them.

Order of the Bath :—

G.C.B.	SMITH, Sir Frank Edward, K.C.B., G.B.E., D.Sc., LL.D., F.R.S.	*Hon. Member.*

Order of Merit :—

	LUTYENS, Sir Edwin Landseer, K.C.I.E., LL.D., D.C.L.	,,

Order of the Indian Empire :—

C.I.E.	LACEY, Gerald, B.Sc.	*Member of Council.*

Order of the British Empire (Military Division) :—

O.B.E.	SHENNAN, John Reginald, M.C., B.Sc.	*Member.*

Order of the British Empire (Civil Division) :—

C.B.E.	BROWN, David Hownam	*Member.*
	ELLSON, George, O.B.E.	,,
	MORGAN, William Henry, D.S.O.	*Member of Council.*
	SWALES, John Kirby, M.C.	*Member.*
	SMITH, Stanley Parker, D.Sc.	*Associate Member.*
O.B.E.	PARKIN, Joseph	*Member.*
	PUGH, Norman John	*Associate Member.*
M.B.E.	COLLETT, Reginald Alfred	*Member.*

Knight Bachelor :—

	ALLEN, Richard William, C.B.E.	*Member.*
	BOOT, Horace Louis Petit	,,
	COOK, Frederick Charles, C.B., D.S.O., M.C.	*Member of Council.*
	DAVIDSON, Jonathan Roberts, C.M.G., M.Sc.	*Former Member of Council.*
	BURT, George Mowlem	*Associate.*

TRANSFERS, ELECTIONS, AND ADMISSIONS.

Since the 16th December, 1941, the following elections have taken place:—

Meeting.	*Members.*	*Associate Members.*
13 January 1942.	2	60

and during the same period the Council have transferred 6 Associate Members to the class of full Members, and admitted 107 Students.

DEATHS.

Bishop, Cecil William Edwin, B.Sc.	*Member.*
Blundell, Harry	,,
Cardew, John Haydon	,,
Jackaman, Charles James	*Associate Member.*
Sainsbury, Graham Wilfred	,, ,,
Seale, Percival Frederic Dreweatt, B.Sc.	,, ,,
*Squire, Samuel Percy	,, ,,
Walrond, Theodore Charles Troubridge	,, ,,
*Blackwell, Leonard Richard	*Student.*
*Bate, John Eglington	,,
*Nairn, James Spence	,,

* On Active Service.

PUBLICATIONS.

A SELECTIVE LIST OF RECENT ADDITIONS TO THE LIBRARY.

[Journals, Proceedings of Societies, etc., are not included.]

Aeronautics. Schütt, K. "Elements of Aeronautics." 1941. Pitman. 12*s*. 6*d*.

Air Conditioning. Carrier, W. H., and others. "Modern Air Conditioning, Heating, and Ventilating." 1940. Pitman. 30*s*.

Aircraft. Morse. "Principles of Aircraft Stressing." 1941. Griffin. 18*s*.

—— Pemberton-Billing, N. "The Aeroplane of To-morrow." 1941. Hale. 12*s*. 6*d*.

Calculus. *See* Mathematics.

Coal. Storch, H. H., and others. "Hydrogenation and Liquefaction of Coal." U.S. Bur. Mines Technical Paper 622. 1941. Supt. of Documents, Washington. 20 cents.

Concrete. American Concrete Institute. A.C.I. Manual of Concrete Inspection." 1941. The Institute, Detroit. 1 dollar.

Education. Richardson, W. A. "The Technical College." 1939. Oxford University Press. 14*s*.

Gears and Gearing. Buckingham, E. "Manual of Gear Design." 3 vols. 1939. Machinery Publishing Co. £4.

*Harbours. Fay, Spofford, and Thorndike. "Notes on the Design of Harbour Structures." 1941. The Authors, Boston, Mass. No price.

Heating. *See* Air Conditioning.

*HYDRAULICS. FREEMAN, J. R. "Flow of Water in Pipes and Pipe-Fittings." 1941. Am. Soc. Mech. E. 48s.

INDUSTRY. DENNISON, S. R. "Location of Industry and the Depressed Areas." 1939. Oxford Univ. Press. 10s.

INSULATION. PITTS, G. Y. "Thermal Insulation of Structures." 1941. Griffin. 10s.

LETTERING. DE GARMO, E. F., and JONASSEN, F. "Technical Lettering." 1941. Macmillan Co., New York. 6s.

MATERIALS. CLARK, D. A. R. "Materials and Structures." 1941. Blackie. 25s.

MATHEMATICS. STEWART, C. A. "Advanced Calculus." 1940. Methuen. 25s.

MECHANICS. TIMOSHENKO, S., and YOUNG, D. H. "Engineering Mechanics." 2nd ed. 1940. McGraw-Hill. 28s.

PAPER MAKING. CLAPPERTON, R. H., and HENDERSON, W. "Modern Paper Making." 2nd ed. 1941. Blackwell. 21s.

PHYSICS. FLEMING, *Sir* A. "Physics for Engineers." 1941. Newnes. 7s. 6d.

STRUCTURES. GODFREY, E. "Structural Tables." 1941. Author, Professional Building, Pittsburgh. 7s. 6d.

—— GRINTER, L. E. "Design of Modern Steel Structures." 1941. Macmillan Co. 26s.

—— *See also* MATERIALS.

TECHNICAL WRITING. OLIVER, L. M. "Technical Exposition." 1940. McGraw-Hill. 10s. 6d.

TRANSFORMERS. STUBBINGS, G. W. "Transformers." 1941. Spon. 12s.

VENTILATION. *See* AIR CONDITIONING.

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* *The foregoing books, with the exception of those marked with an asterisk, may be borrowed from the Loan Library.*

LOCAL ASSOCIATIONS.

The following arrangements have been made for forthcoming meetings of the Local Associations. The arrangements are in the hands of the Committees of the Associations concerned and all communications respecting them should be addressed to the respective Honorary Secretaries :—

EDINBURGH AND DISTRICT ASSOCIATION.

Mar. 11. Film illustrating the Failure of the Tacoma Narrows Suspension Bridge.

NORTHERN IRELAND ASSOCIATION.

Feb. 23. "Town Re-planning", by Captain Brown.
Mar. 30. Meeting to be arranged.
Apr. 27. Annual General Meeting.

NORTH-WESTERN ASSOCIATION.

Mar. 21. "Soil Mechanics and Site Exploration", by L. F. Cooling, M.Sc.
Apr. 25. "Post War Planning and Reconstruction", by H. J. Manzoni, C.B.E., M. Inst. C.E.

SOUTH WALES AND MONMOUTHSHIRE ASSOCIATION.

Feb. 21. "The Construction of an Arch Dam for Temporary Work", by J. A. Posford, M.A., Assoc. M. Inst. C.E. (at Swansea).

Apr. 18. Annual General Meeting (at Cardiff).

YORKSHIRE ASSOCIATION.

Feb. 28. Film illustrating the Failure of the Tacoma Narrows Suspension Bridge (at Sheffield).

Mar. 7. Joint meeting with the Yorkshire Association of the Institution of Mechanical Engineers. The Thomas Hawksley Lecture on "A Century of Tunnelling", by W. T. Halcrow, M. Inst. C.E., Member of Council (at Sheffield).

REPORTS.

Edinburgh and District Association.

On Wednesday, 14 January, a Paper on "Planning for Agriculture and Industry in the Lothians" was read by Mr. F. C. Mears, F.R.I.B.A.

Northern Ireland Association.

On Monday, 24 November, Lieut. John Mansbridge, R.E., read a Paper on "Camouflage."

North-Western Association.

The film illustrating the Failure of the Tacoma Narrows Suspension Bridge was exhibited at a meeting held on Saturday, 3 January.

Southern Association.

On Saturday, 13 December, at Portsmouth, Papers on "Static Water Basins", by W. E. C. Chamberlain, Assoc. M. Inst. C.E., and "Deep Tunnel Air Raid Shelters", by Donald Exley, Assoc. M. Inst. C.E., were read, and in connexion with these Papers various works in the district were visited by members of the Association during the afternoon.

SYNOPSIS OF A PAPER FOR DISCUSSION.

The following Paper will be brought forward for discussion on the date indicated in the margin of the synopsis, and will be published, with reports of the oral and written discussions upon it, in the Journal. Members desiring to take part in the consideration of the Paper should apply forthwith for advance copies, which will be forwarded as soon as they are ready. Applications for proofs should be made on postcards, quoting the number of the Paper.

A period of about 3 months from the date of publication of the Paper
the Journal is generally allowed for written communications, which
ould be :—

(*a*) As concise as possible, entirely relevant to the subject-matter of the Paper, and consist of not more than 1,000 words ;
(*b*) Written legibly or typed with the lines openly spaced.

Paper No. 5310.

"The Surface Finishing of Concrete Structures."

Date of Discussion 10/3/42.

By NORMAN DAVEY, B.Sc., Ph.D., M. Inst. C.E.

The purpose of the Paper is to emphasize the importance of surface
nishing of concrete. Reference is made to the conclusions drawn from
vestigations carried out on the subject by the Building Research Station
collaboration with the Cement and Concrete Association and such
ctors as control of mix, design of formwork, method of placing, con-
ruction joints, types of finish, conditions of exposure, and general archi-
ctural considerations are dealt with.

LATE NOTICE.

An Extra General Meeting of the Institution of Mechanical Engineers
ill be held on Friday, 27 February, at 2.30 p.m., at Storey's Gate,
estminster, S.W.1., when a Paper entitled "Proneness to Damage of
lant through Enemy Action" will be presented for Discussion by the
uthor, Mr. Hal Gutteridge, M. I. Mech. E. By courtesy of the
ist. Mech. E. Members of the Inst. C.E. are invited to attend the Meet-
g, and any members who wish to be present should sign the visitors'
st before entering.

Advance proofs will be available on application to the Secretary,
ist. Mech. E.

[illegible] period of which had been devoted to the discussion of the Paper [illegible] Journal is encouraged [illegible] communications which [illegible] be:—

(a) As concise as possible, strictly relevant to the subject-matter of the Paper, and [illegible] of not more than 1,000 words;

(b) Written legibly or typed with the lines openly spaced.

Paper No. [illegible]

"The Surface Finishing of Concrete Structures."

By [illegible]

[illegible] purpose of the Paper is to [illegible] of surfaces [illegible] [illegible]

EXTRA MEETING.

[illegible] Extra General Meeting of the Institution of Mechanical Engineers [illegible] held on Friday, 27 February, at 5.30 p.m., at Storey's Gate, [illegible] when a Paper entitled "[illegible]" will be presented [illegible] [illegible] Members of the Inst. C.E. are invited to attend the Meeting, and any members who wish to be present should [illegible] before entering.

[illegible] will be available on application to the Secretary, [illegible]